

US010709206B2

(12) **United States Patent**  
**Walker et al.**

(10) **Patent No.:** **US 10,709,206 B2**  
(45) **Date of Patent:** **Jul. 14, 2020**

(54) **METHOD OF FILLING  
ELECTRORHEOLOGICAL FLUID  
STRUCTURE**

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(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 237 days.

(21) Appl. No.: **15/363,436**

(22) Filed: **Nov. 29, 2016**

(65) **Prior Publication Data**

US 2017/0150785 A1 Jun. 1, 2017

**Related U.S. Application Data**

(60) Provisional application No. 62/260,897, filed on Nov.  
30, 2015.

(51) **Int. Cl.**

**A43D 63/00** (2006.01)  
**A43B 13/20** (2006.01)  
**A43B 13/18** (2006.01)  
**A43D 999/00** (2006.01)  
**A43B 3/00** (2006.01)  
**B65B 31/02** (2006.01)

(52) **U.S. Cl.**

CPC ..... **A43D 63/00** (2013.01); **A43B 3/0005**  
(2013.01); **A43B 13/189** (2013.01); **A43B**  
**13/20** (2013.01); **A43D 999/00** (2013.01);  
**B65B 31/02** (2013.01)

(58) **Field of Classification Search**

USPC ..... 219/766  
See application file for complete search history.

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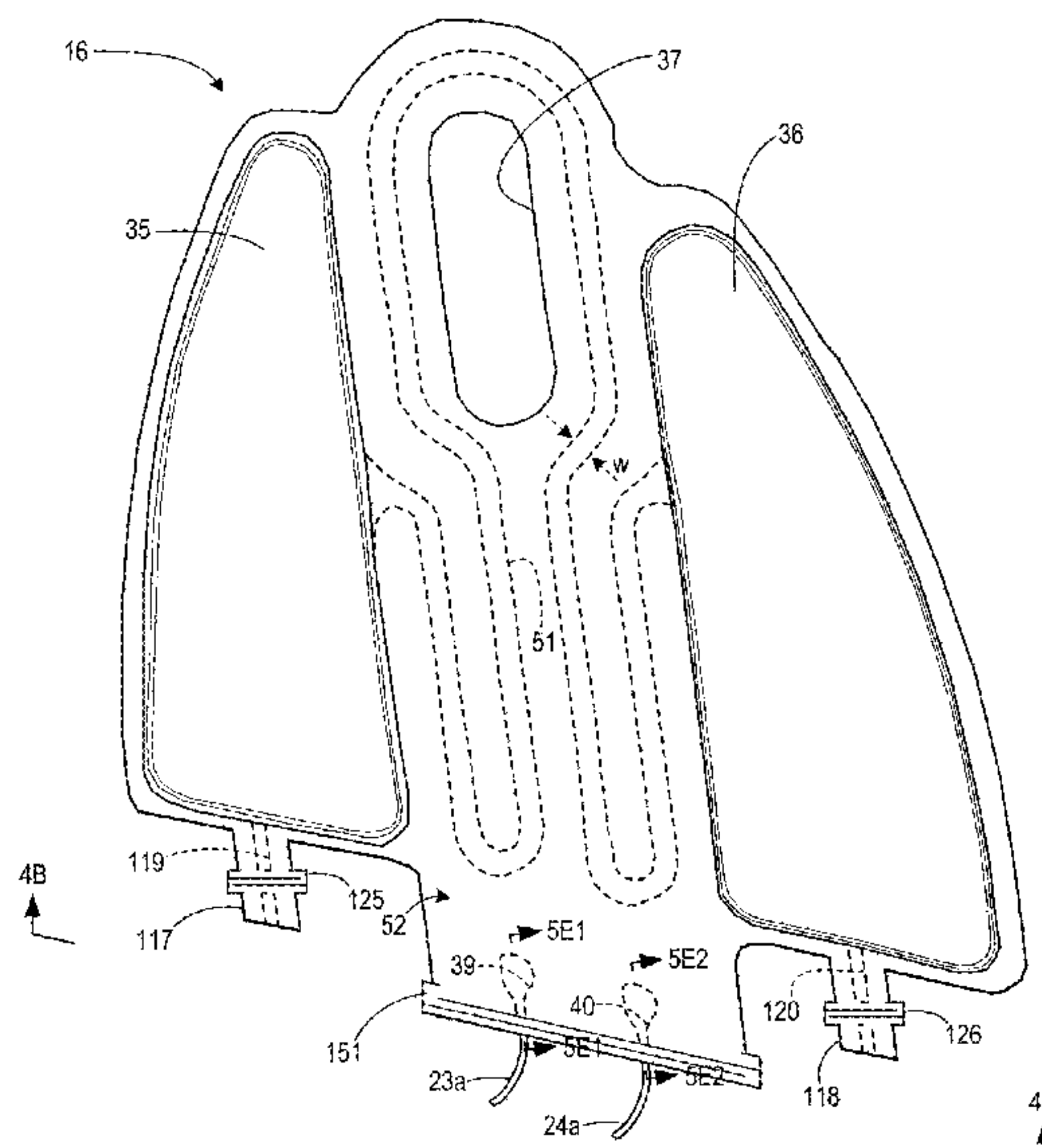
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**ABSTRACT**

A housing of an incline adjuster may include a medial fluid chamber in fluid communication with a lateral fluid chamber through a serpentine transfer channel. The housing of the incline adjuster may include channels through which electrorheological fluid may be injected into the chambers. A method of filling an electrorheological fluid structure may include introducing electrorheological fluid into an interior volume of a housing. The electrorheological fluid within the housing may then be subjected to a sub-atmospheric pressure. Subsequently, the interior volume may be sealed relative to an exterior of the housing.

**12 Claims, 27 Drawing Sheets**



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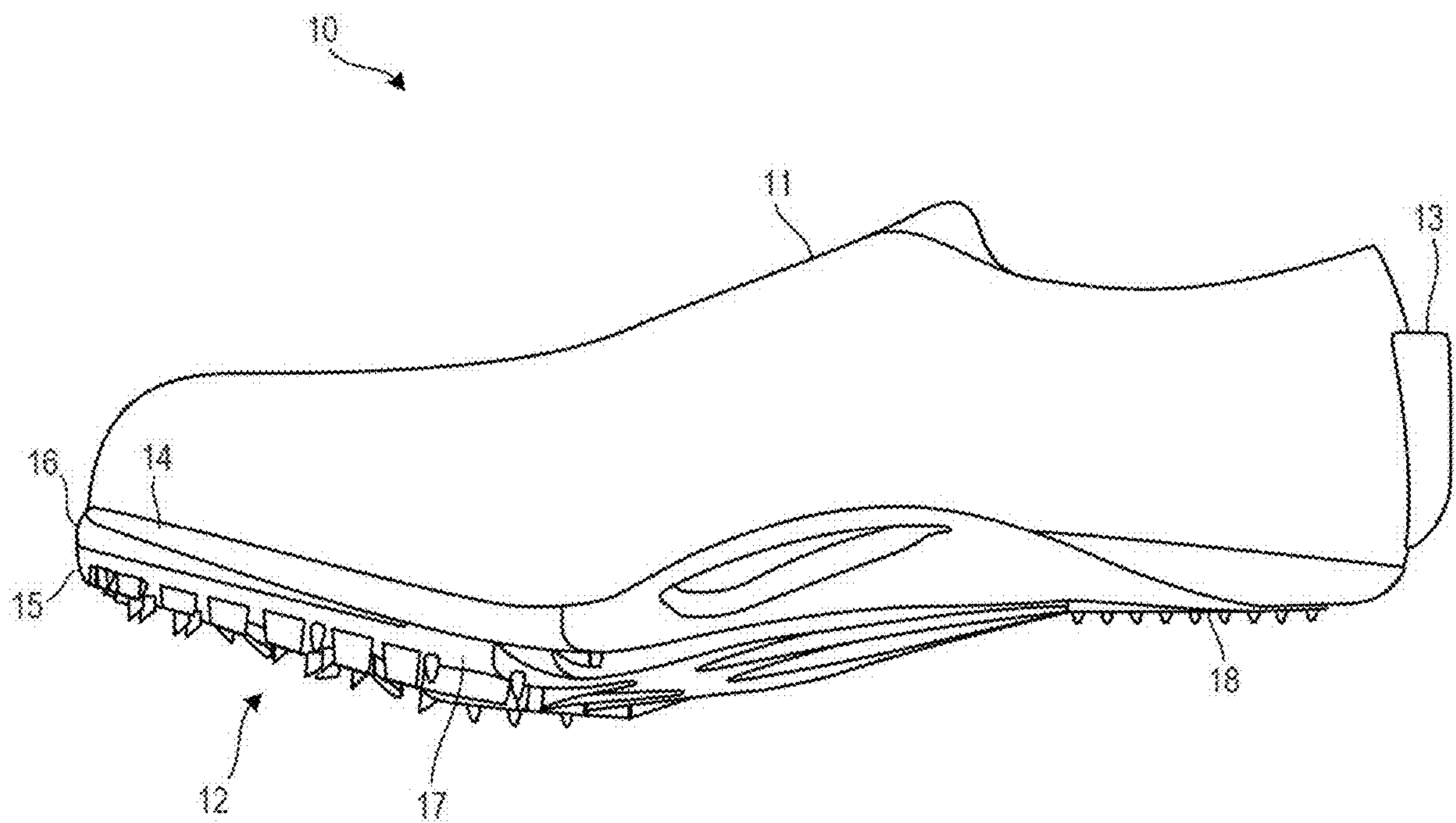


FIG. 1

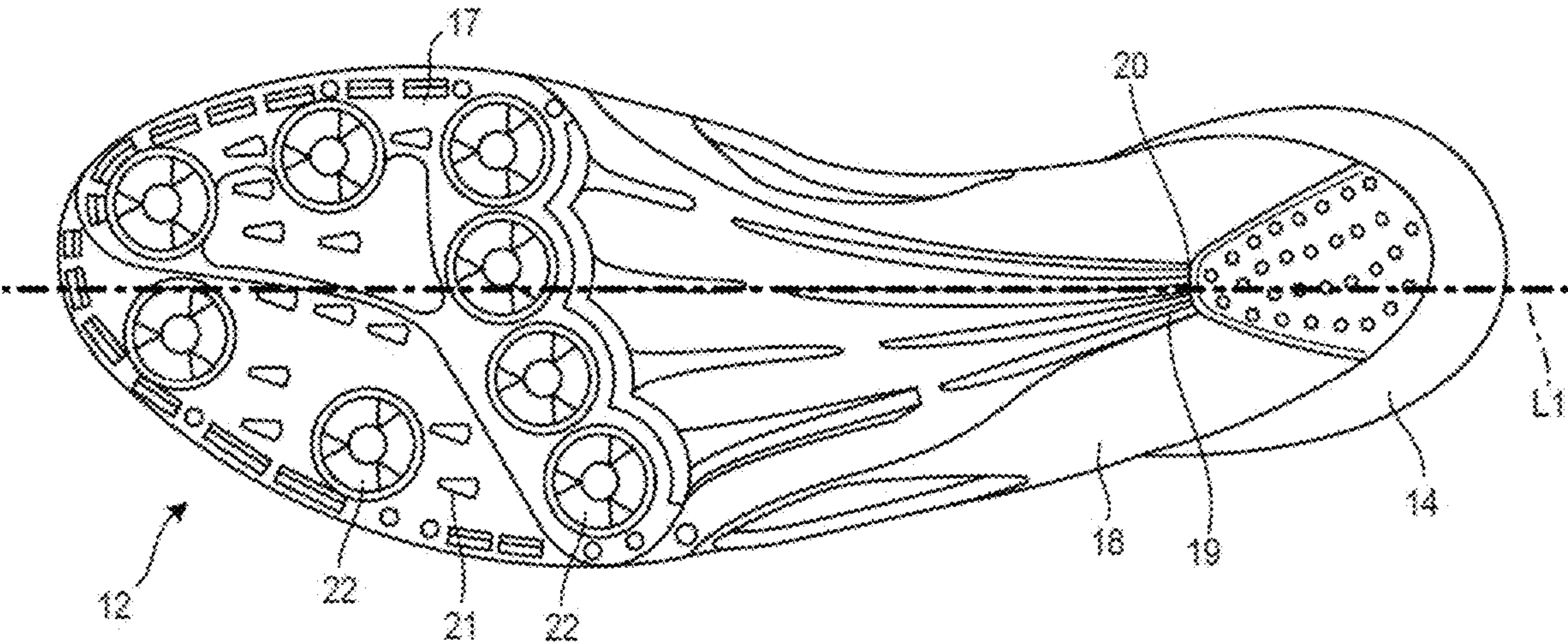


FIG. 2A

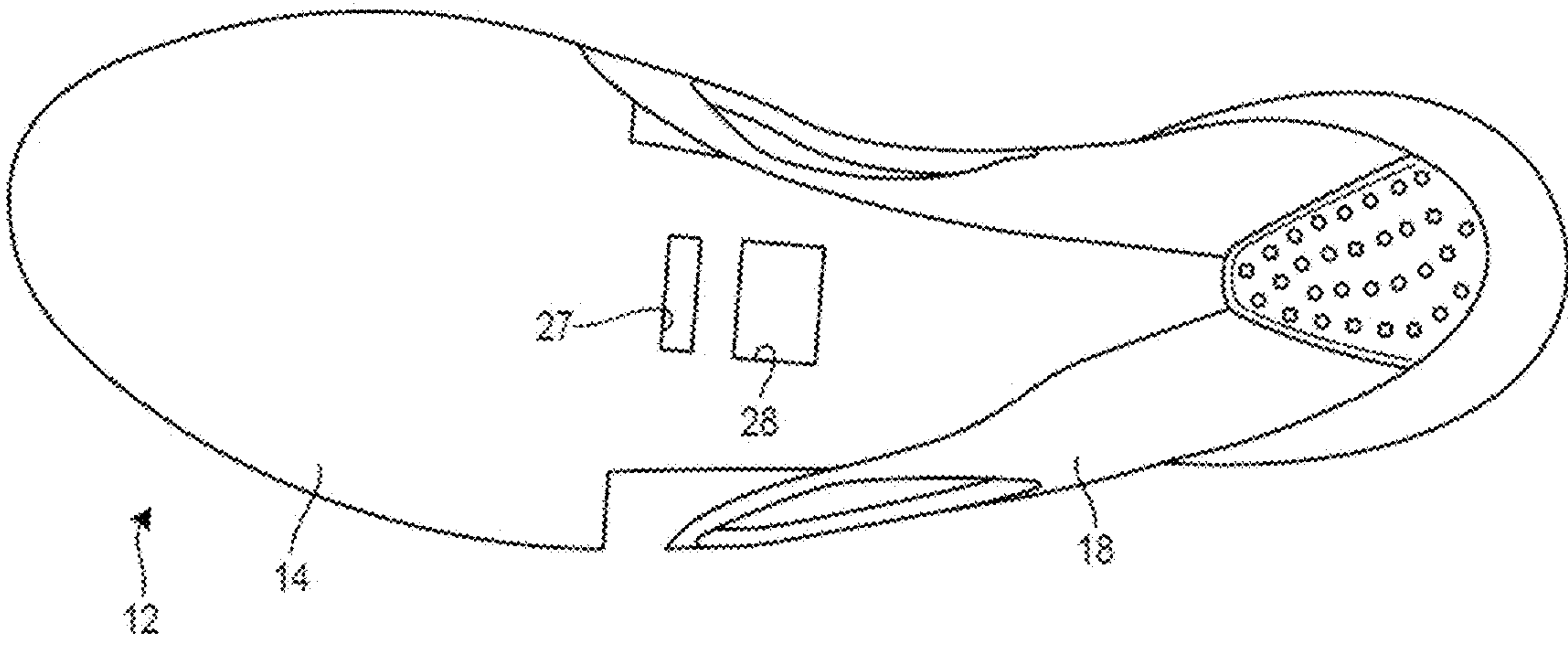


FIG. 2B

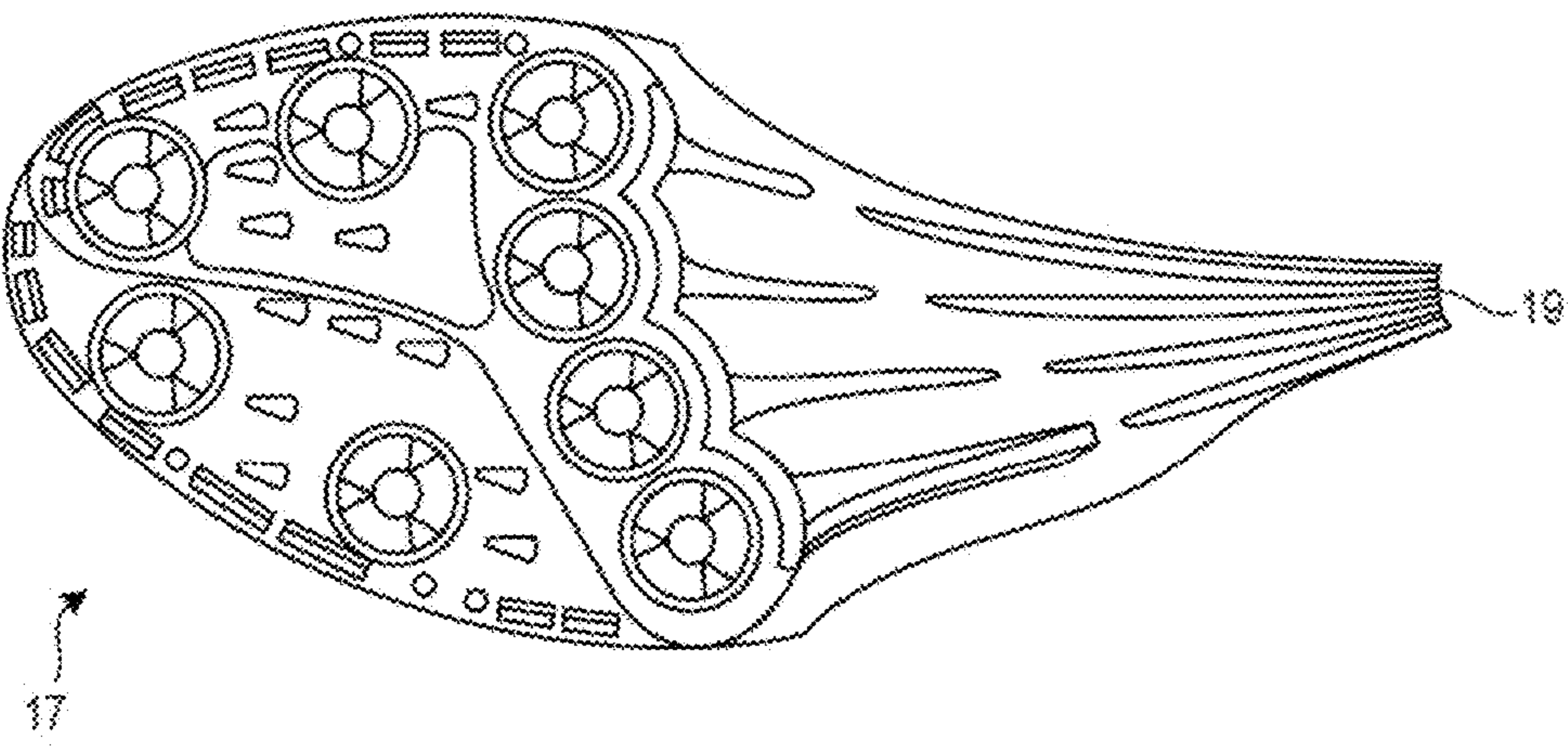


FIG. 2C

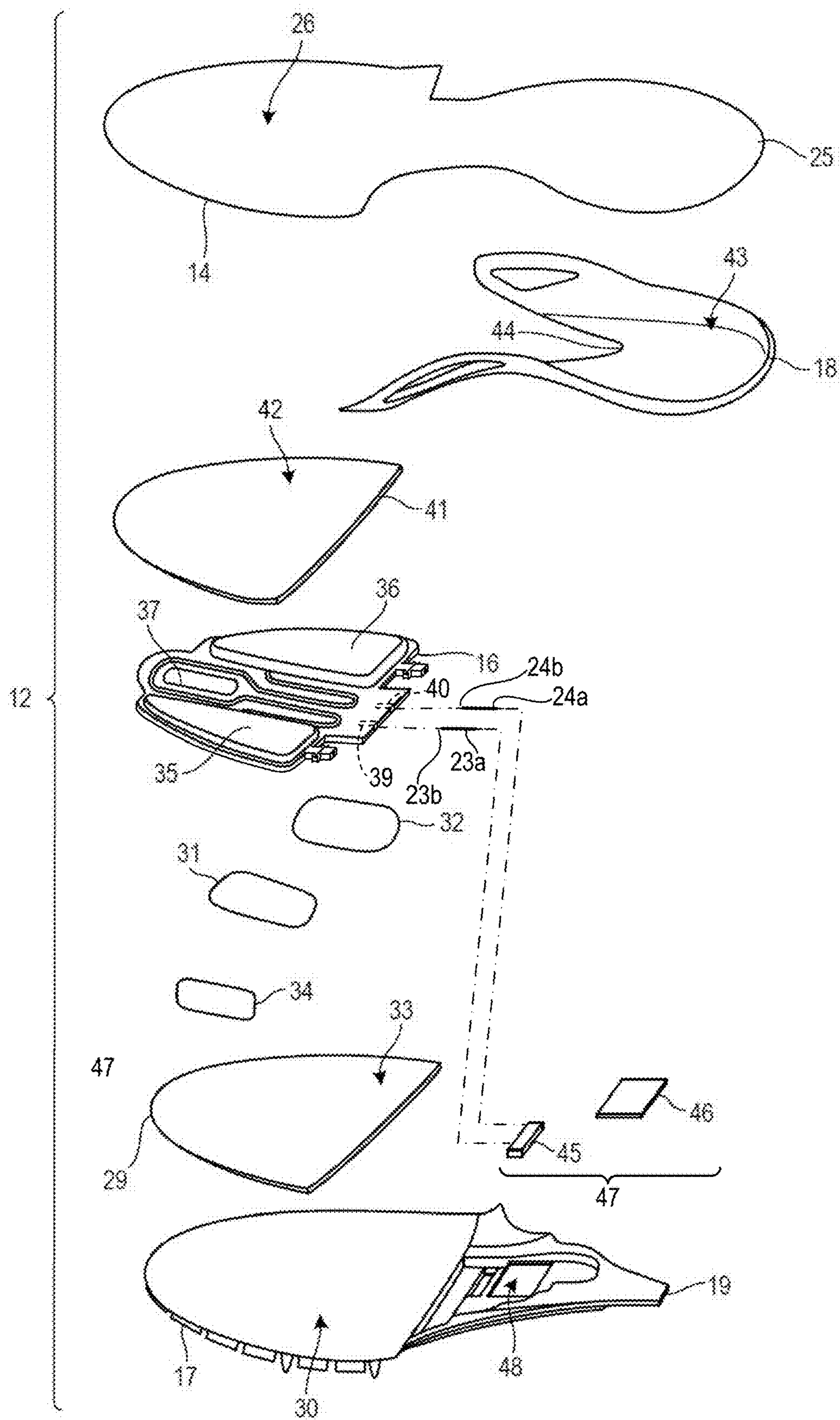


FIG. 3



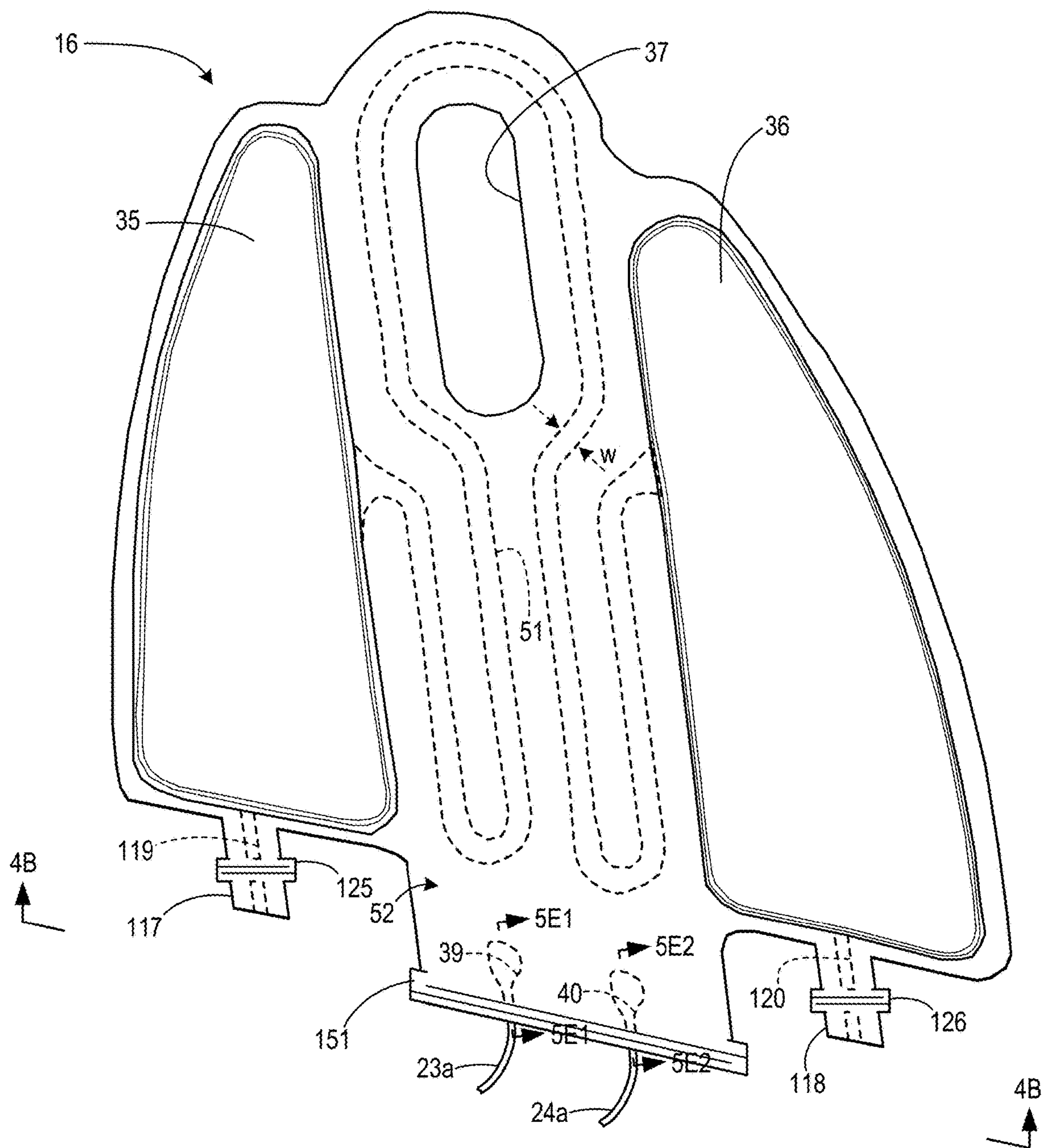


FIG. 4A

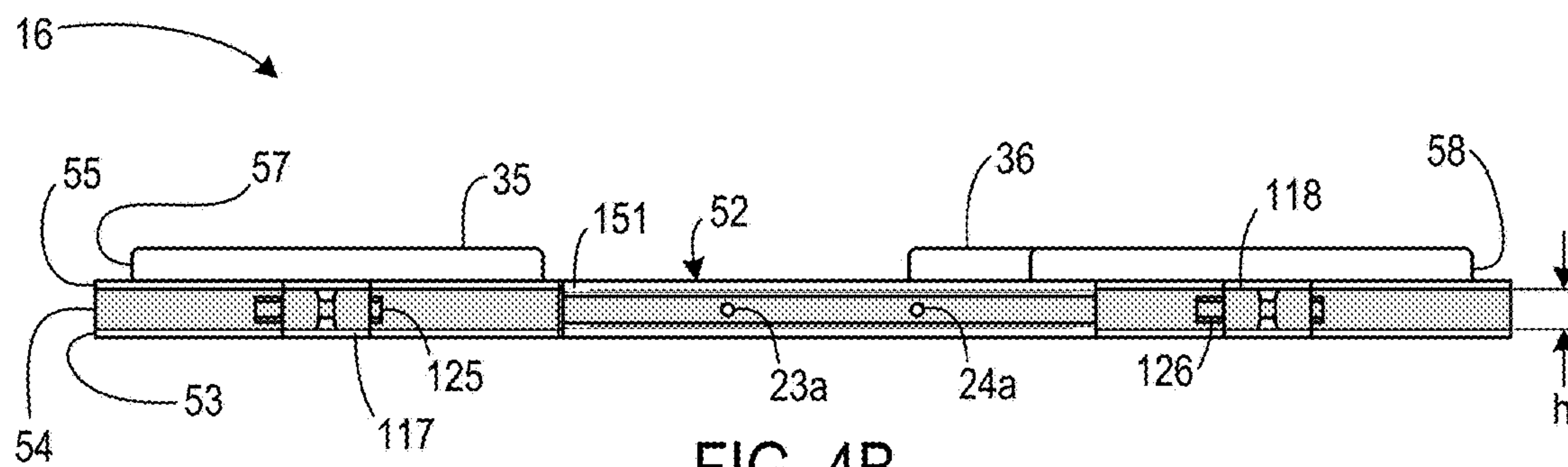


FIG. 4B

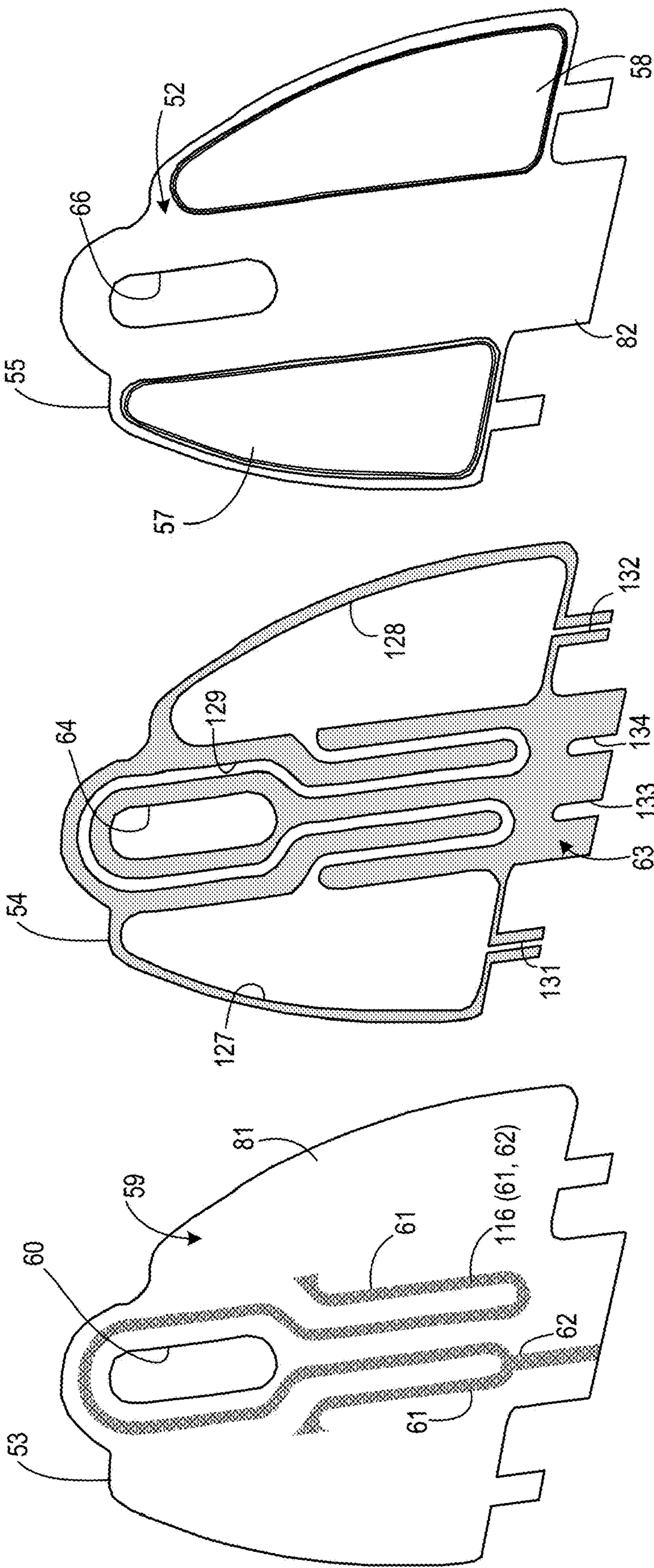


FIG. 5C1

FIG. 5B

FIG. 5A

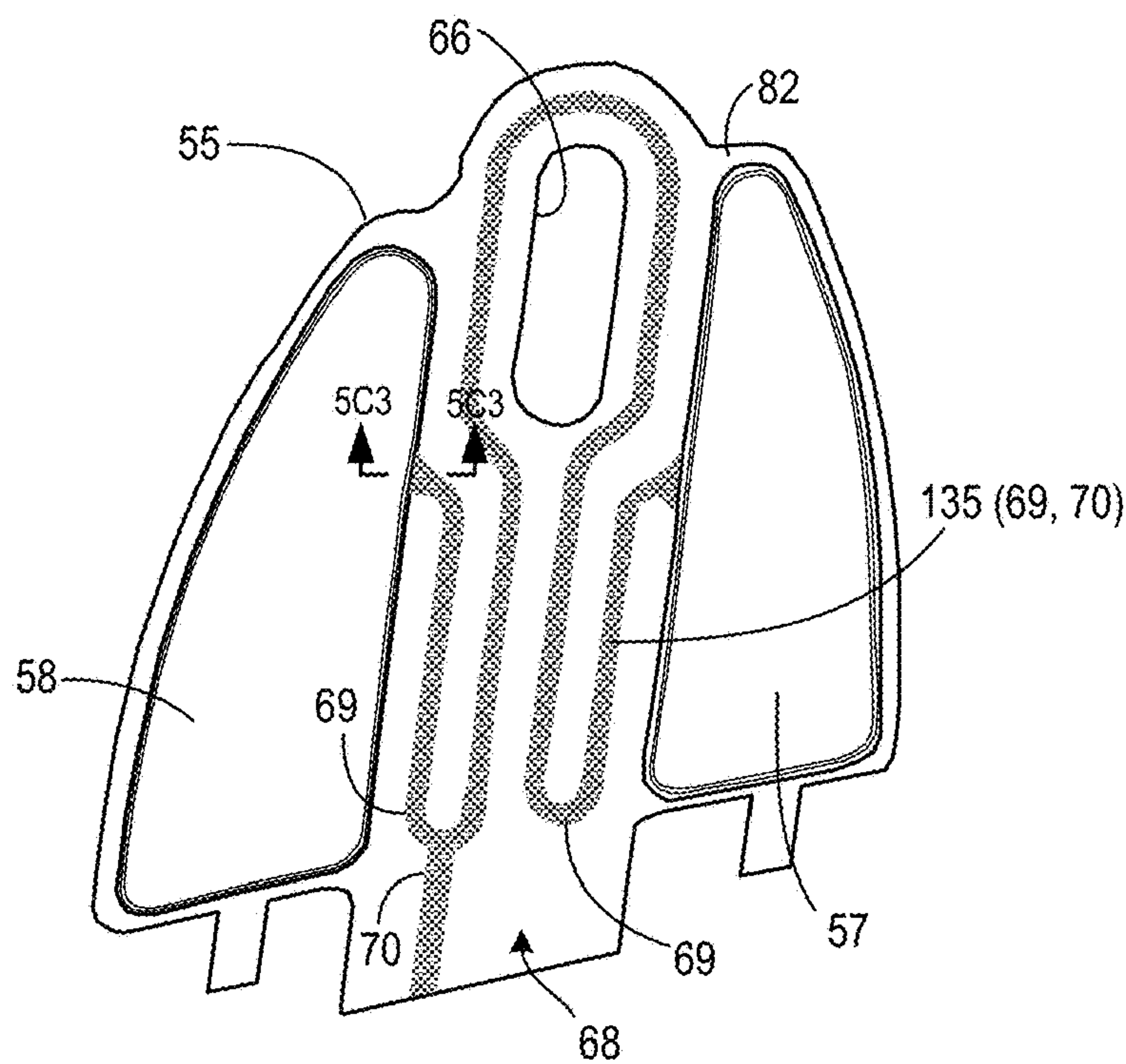


FIG. 5C2

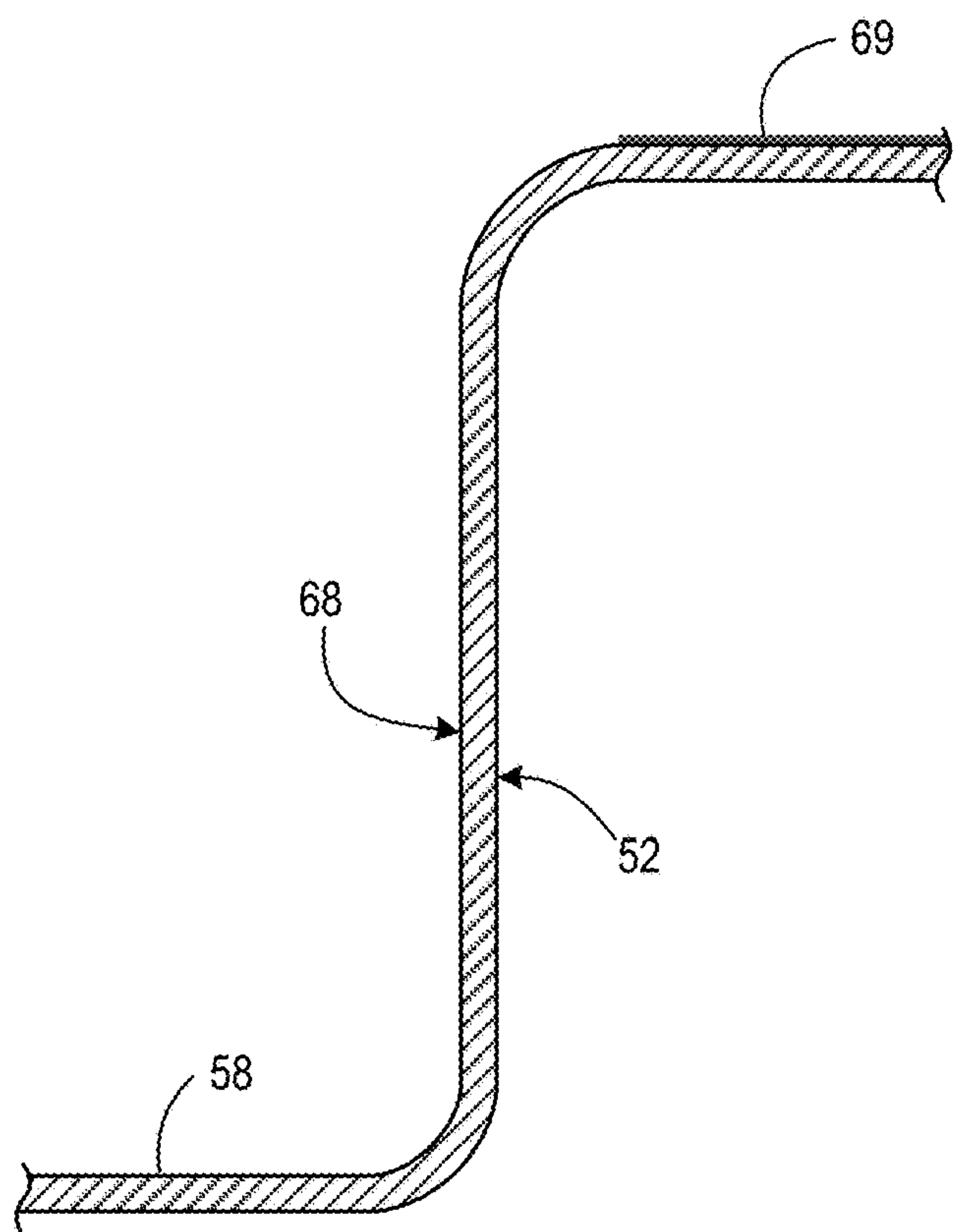


FIG. 5C3



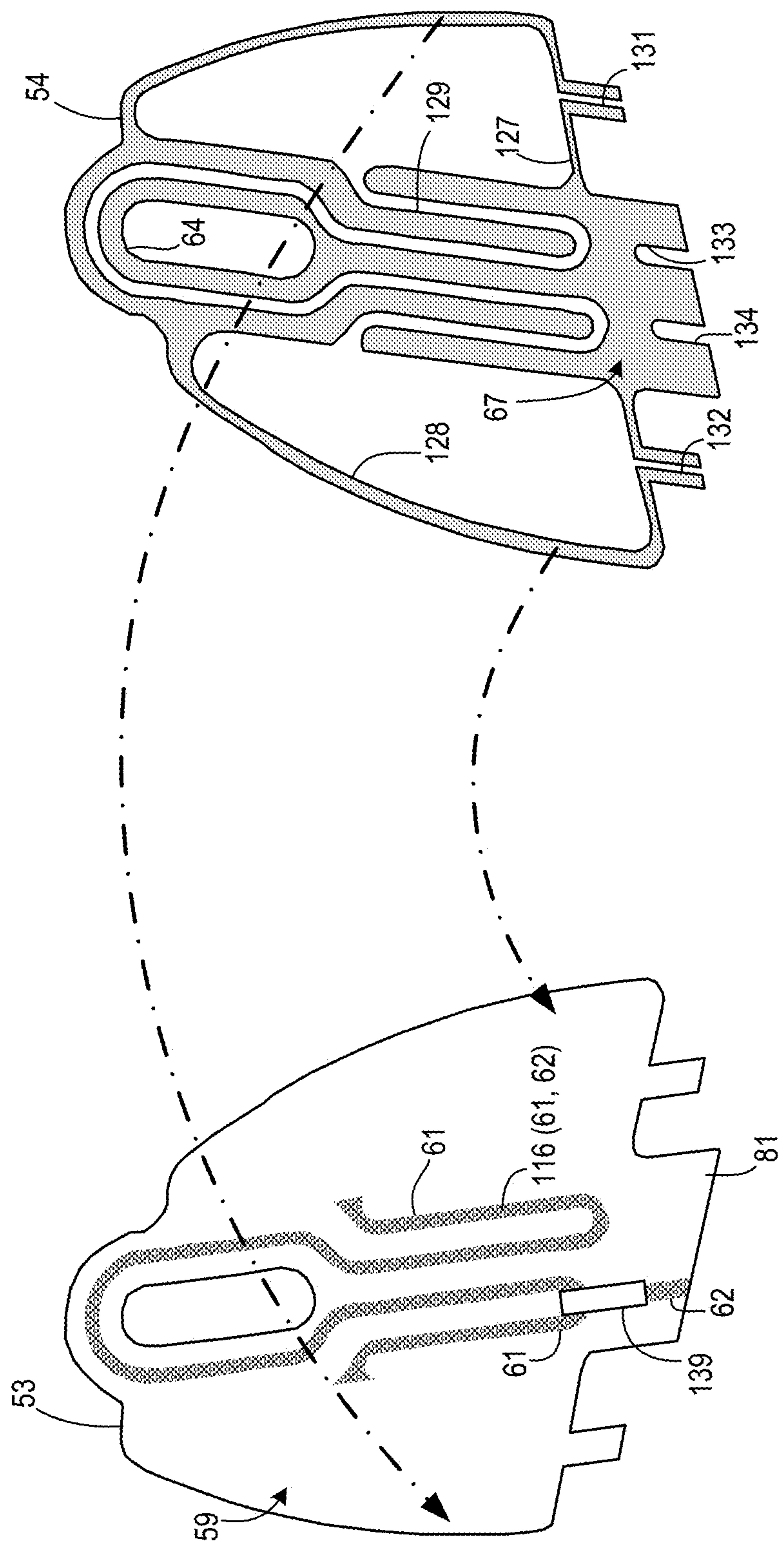


FIG. 5D1

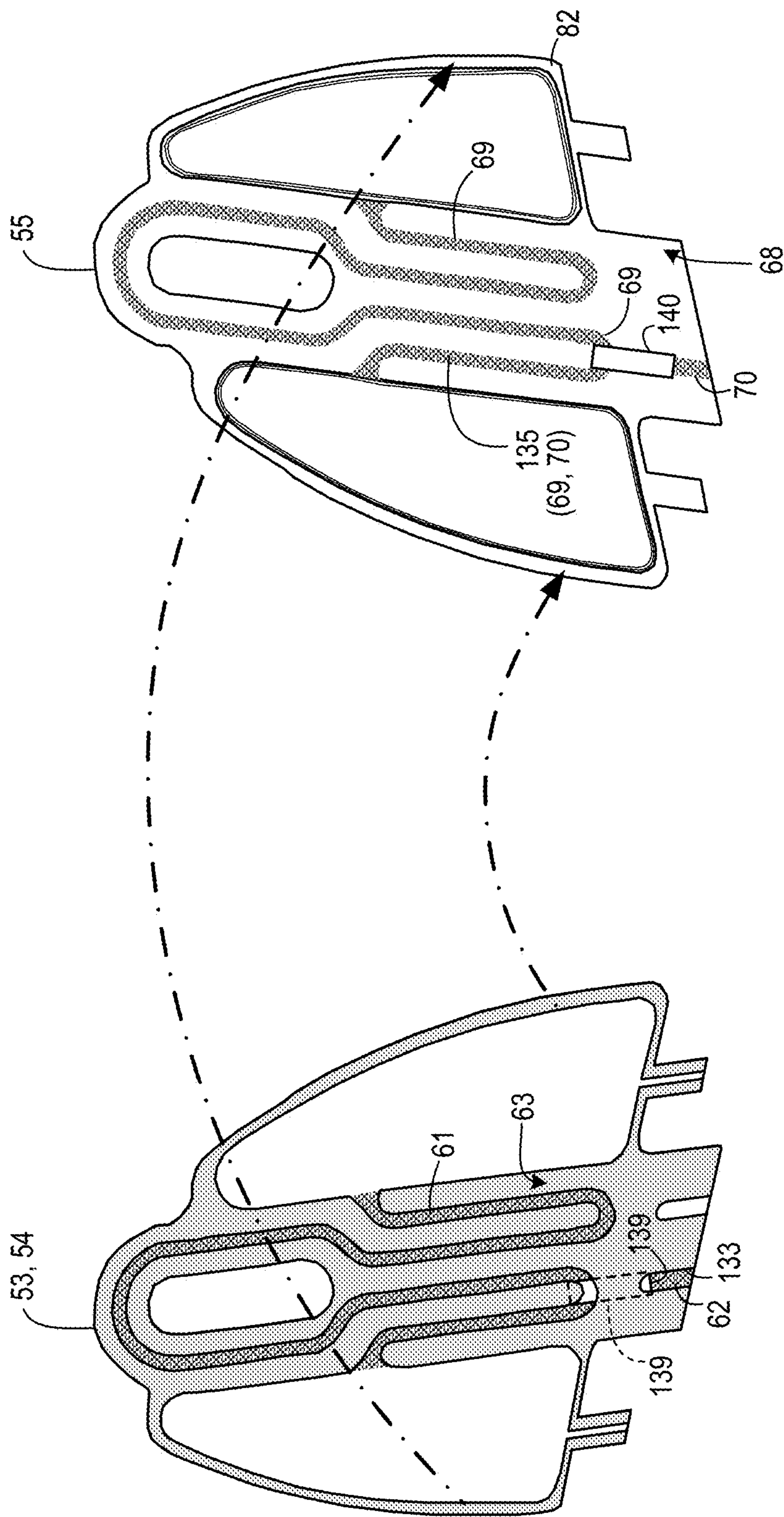


FIG. 5D2



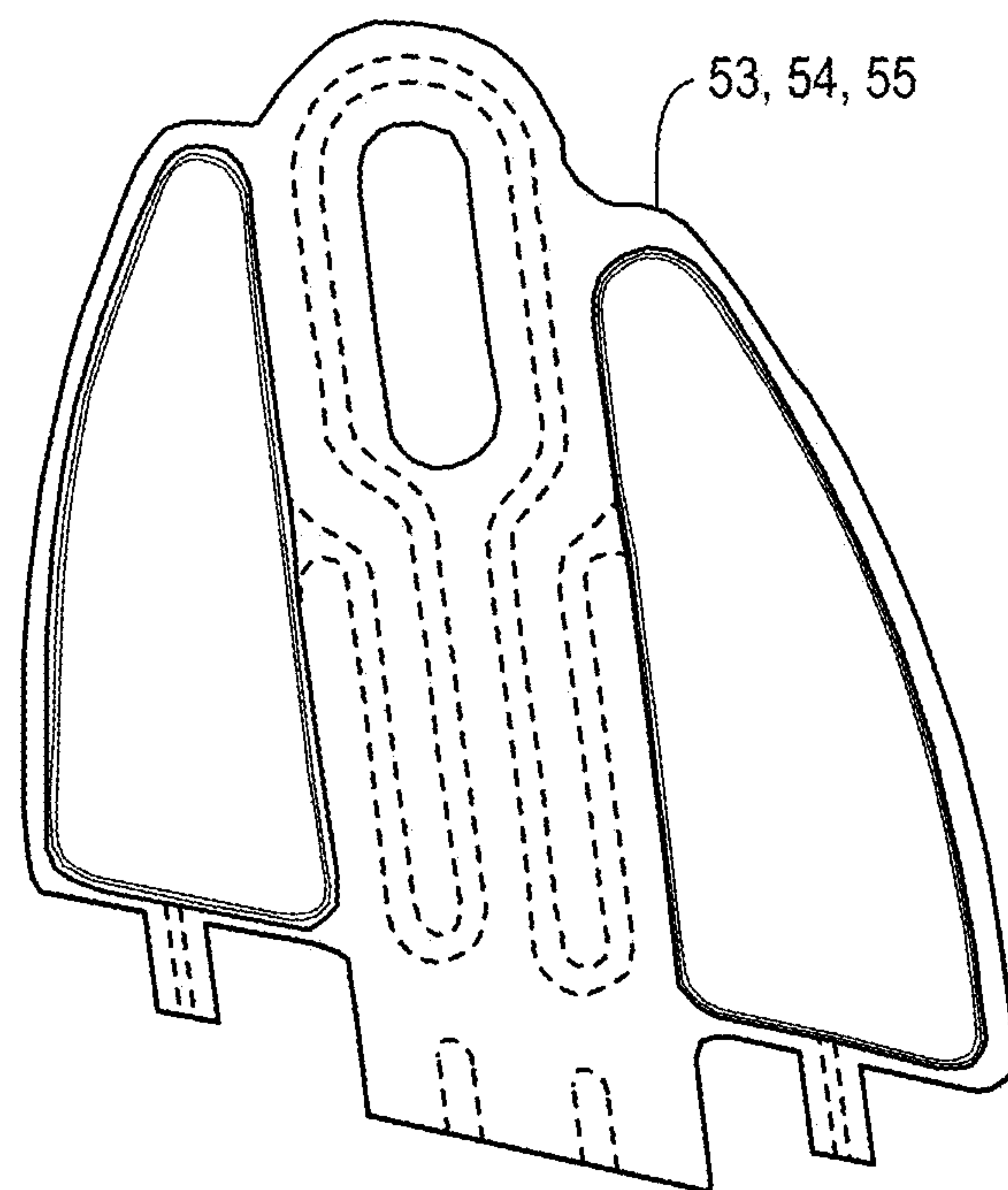


FIG. 5D3

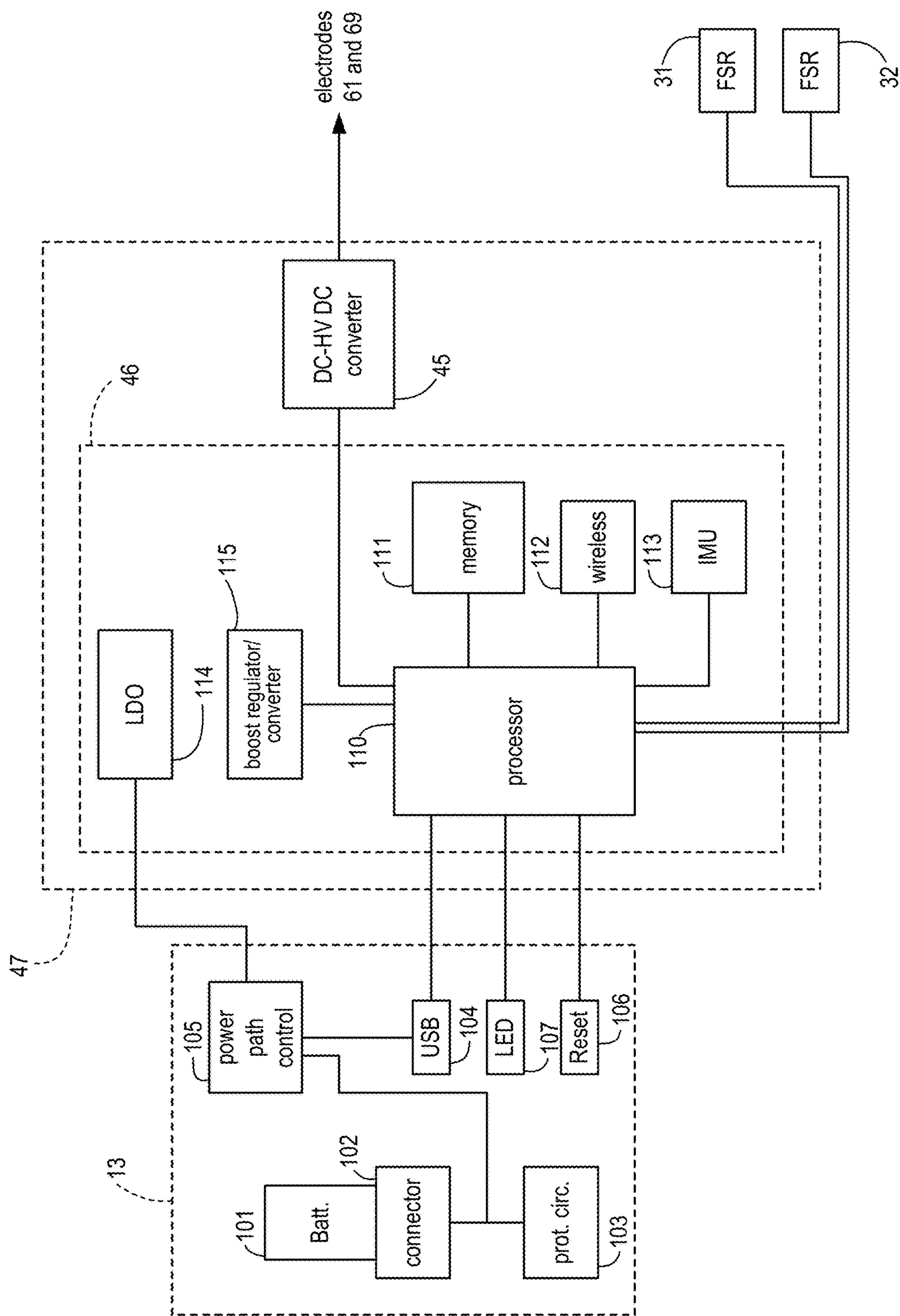
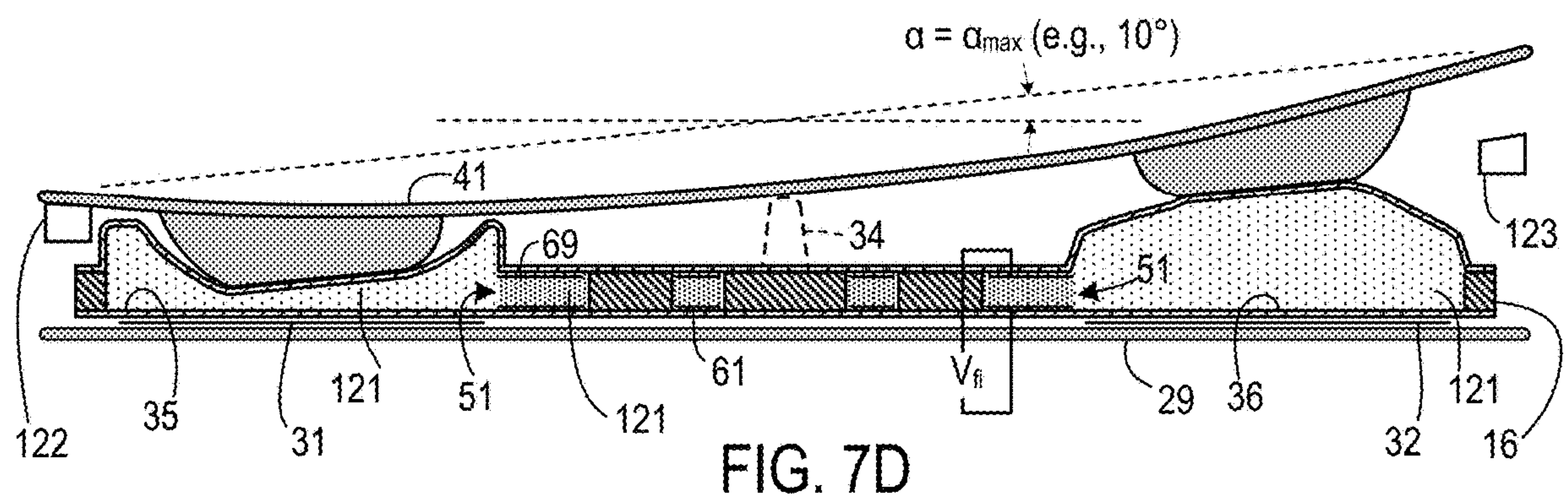
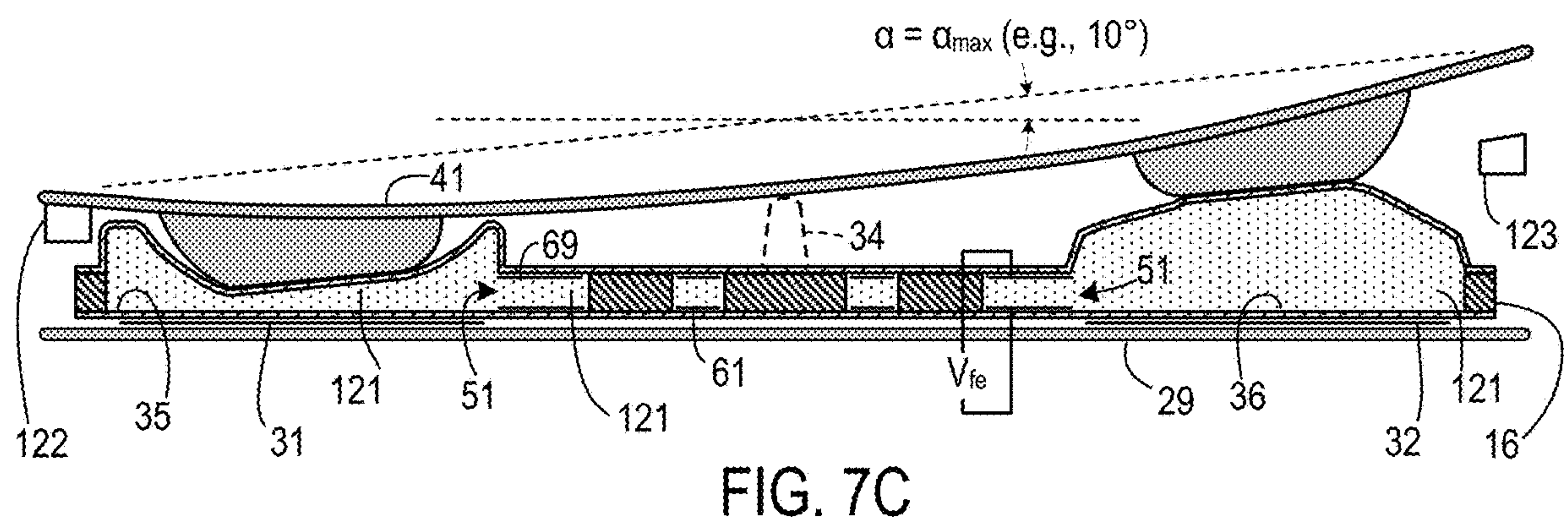
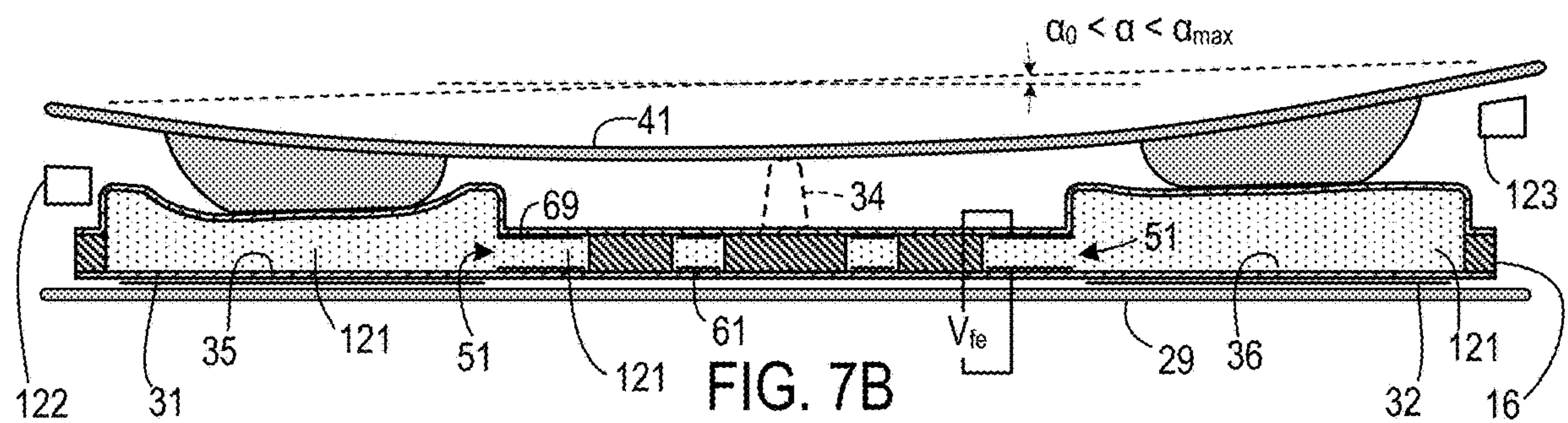
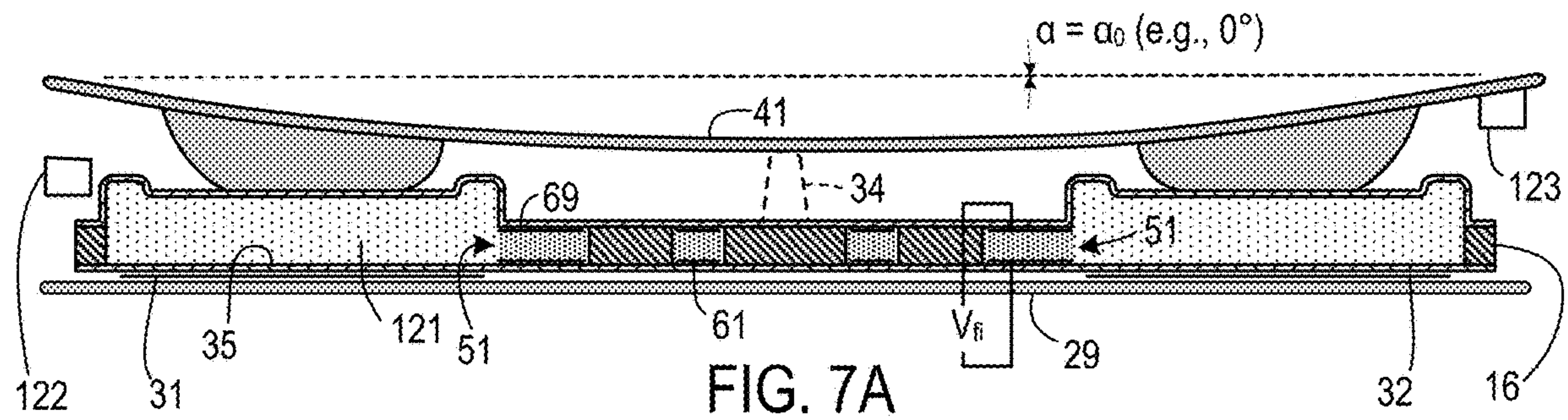


FIG. 6





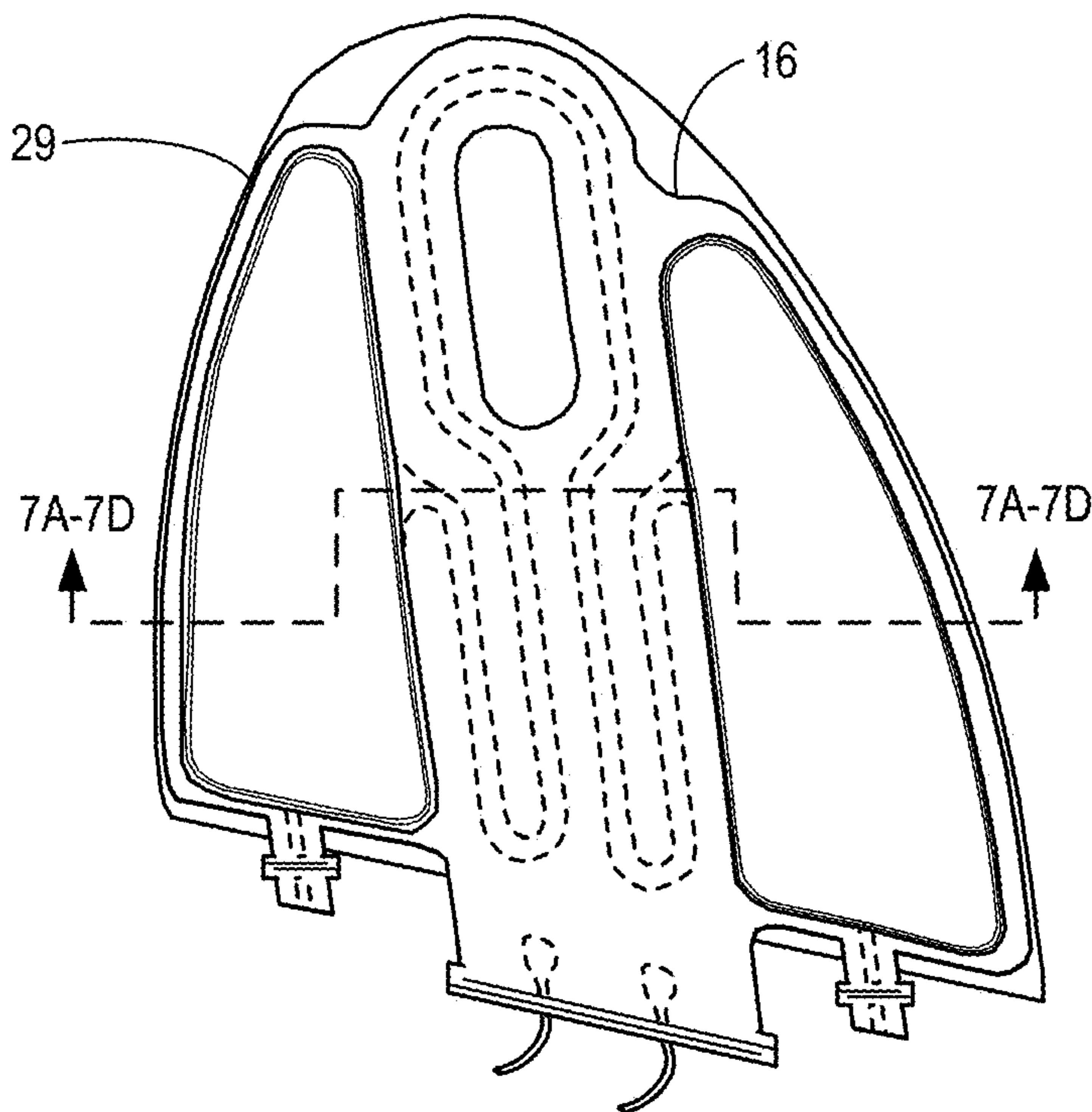


FIG. 7E



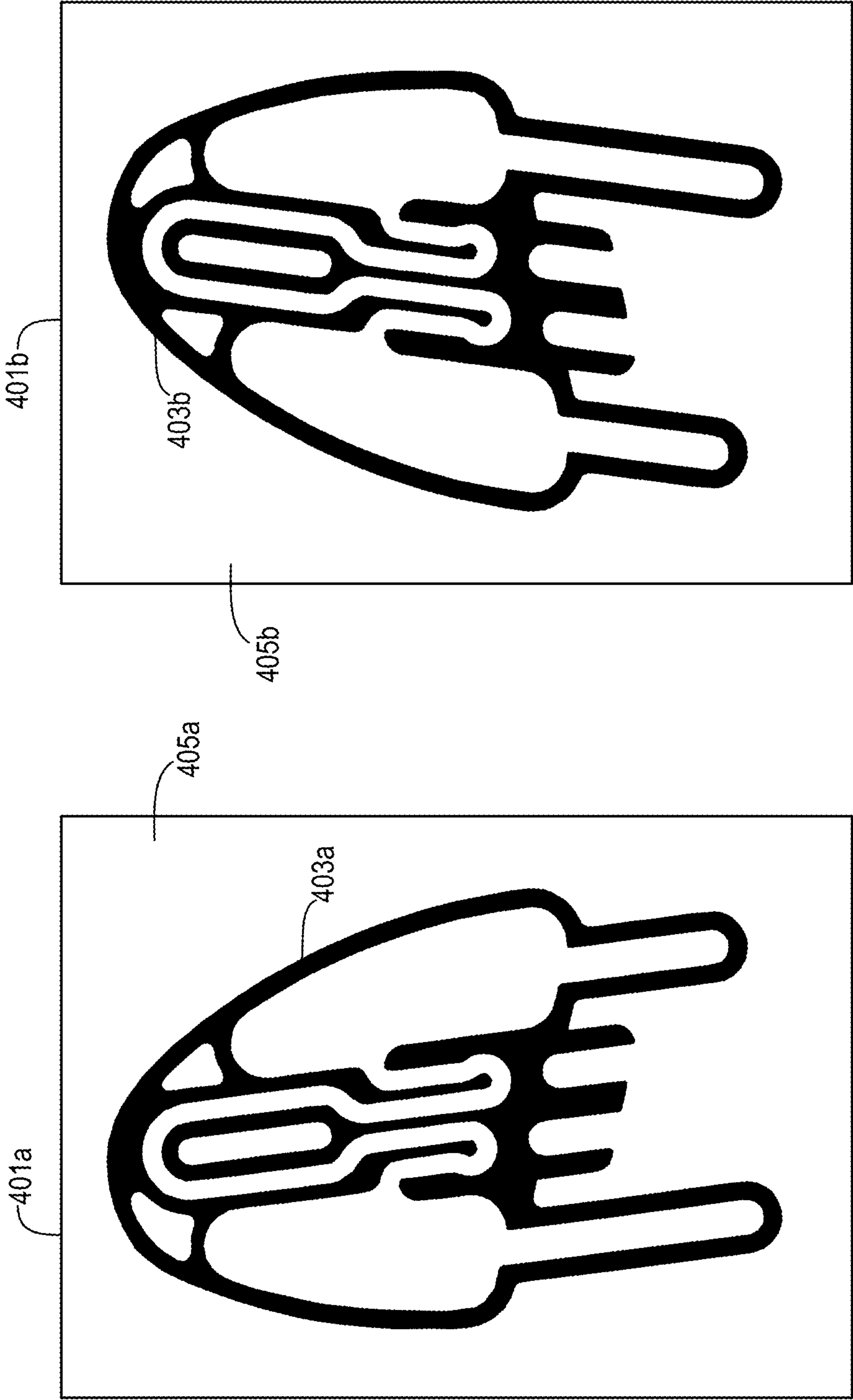


FIG. 8A

FIG. 8B

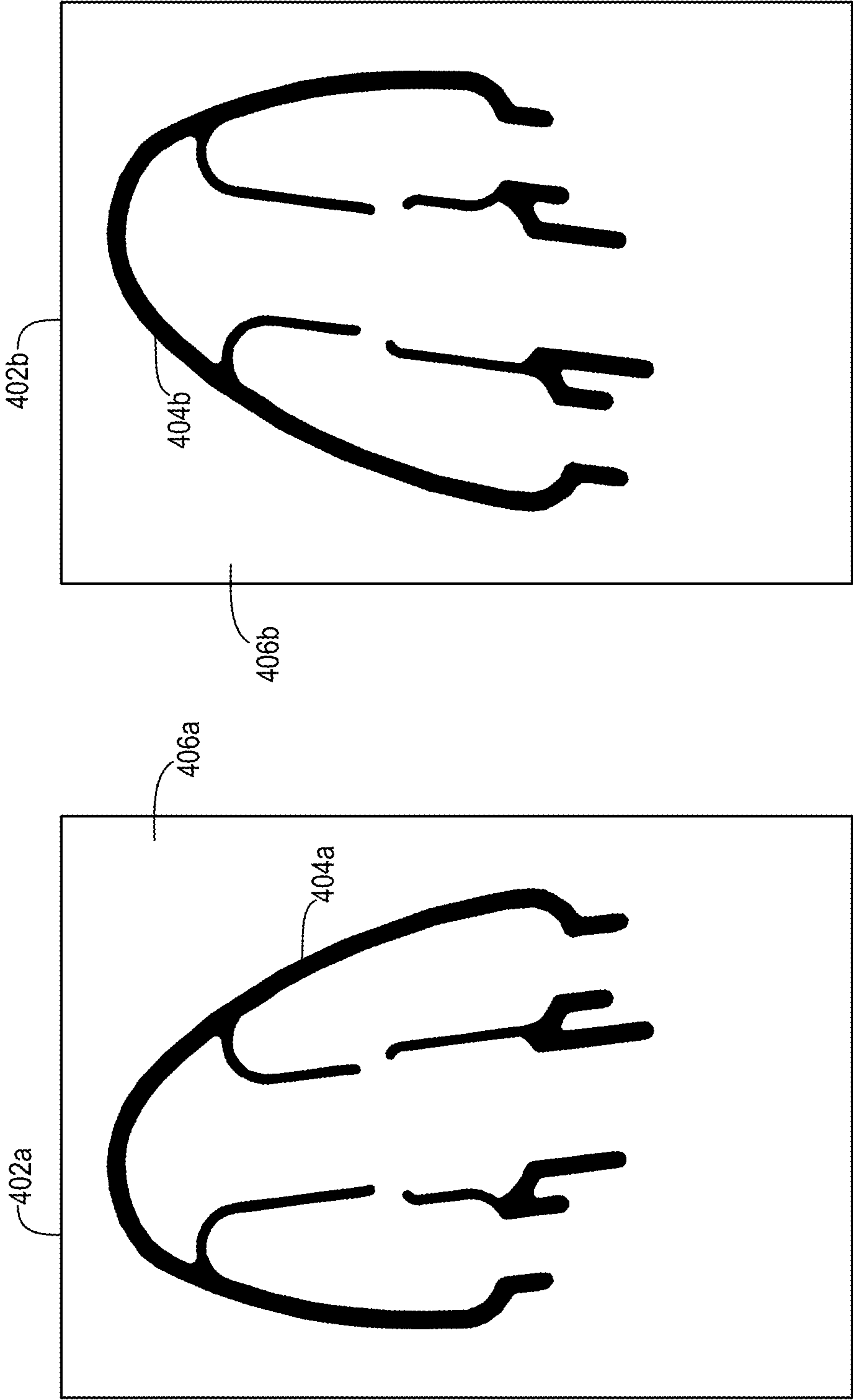


FIG. 8C

FIG. 8D



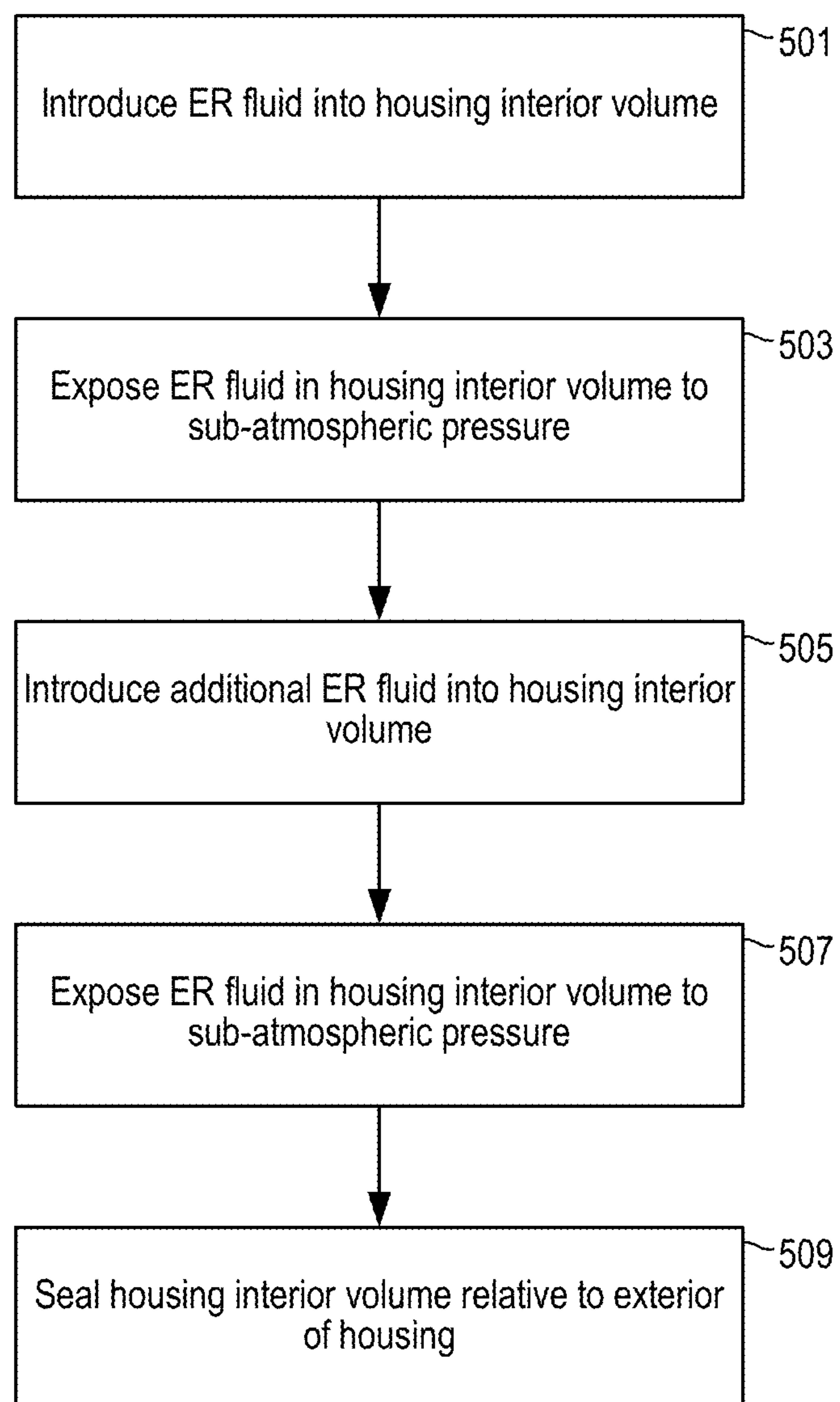


FIG. 9

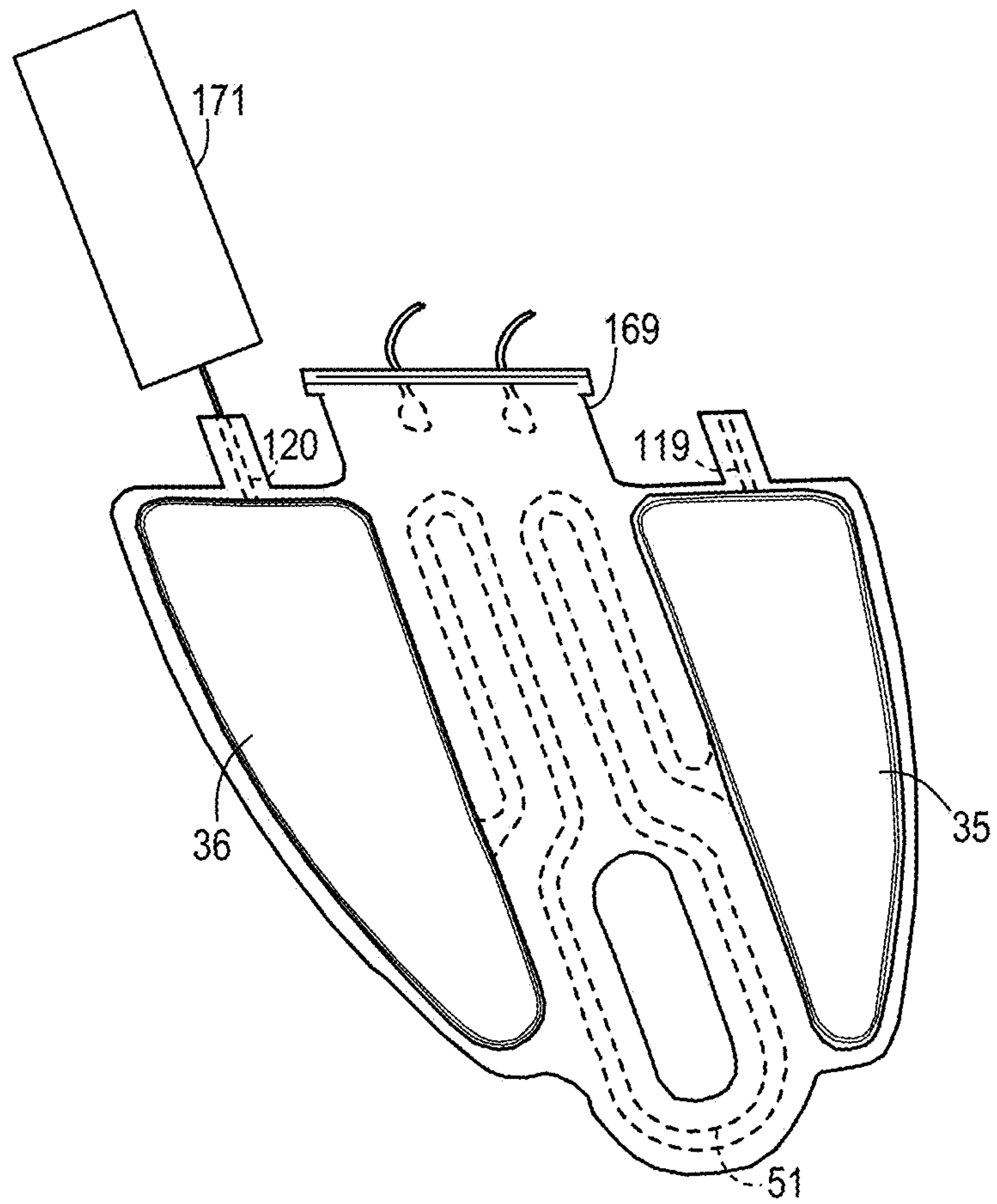


FIG. 10A

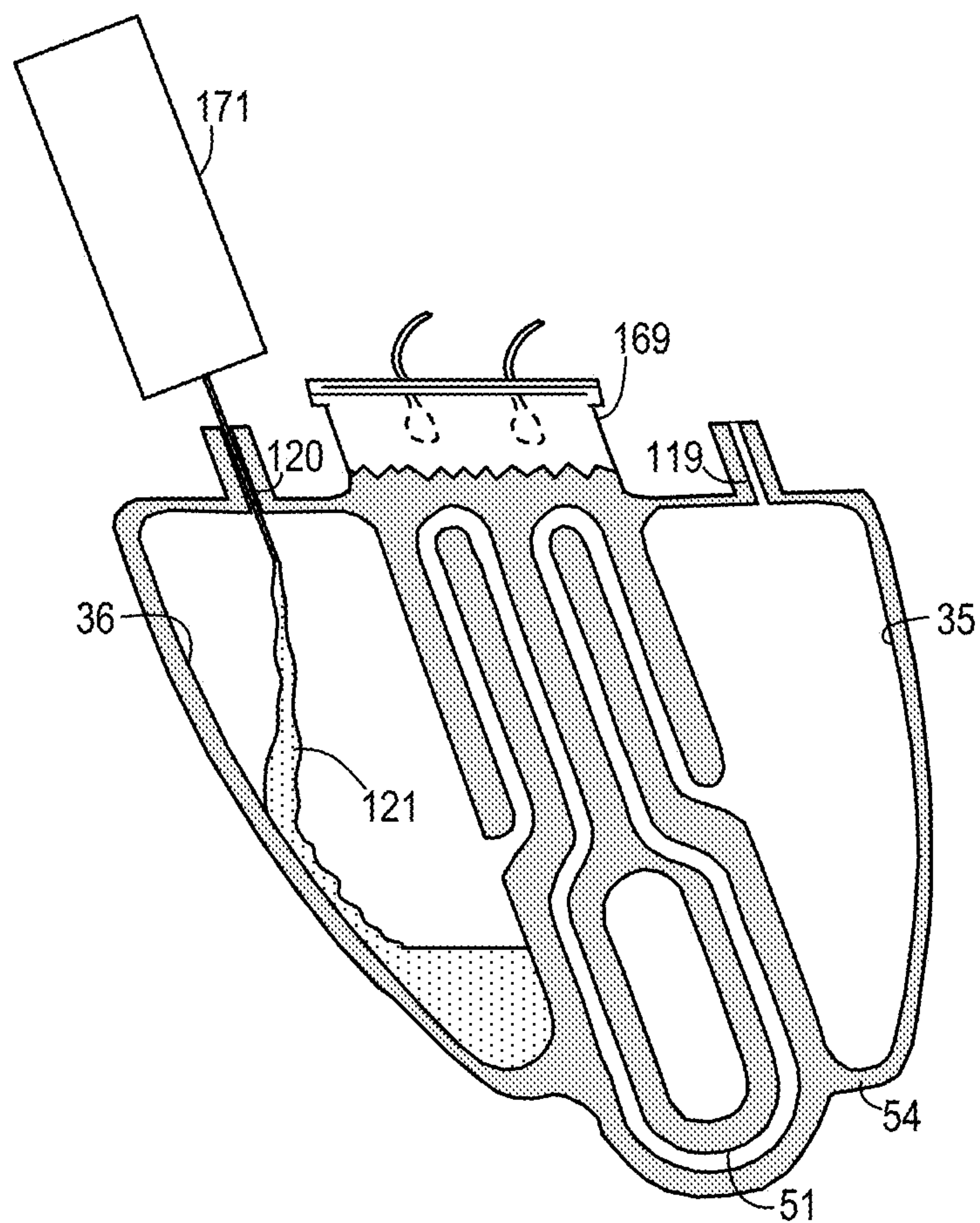


FIG. 10B



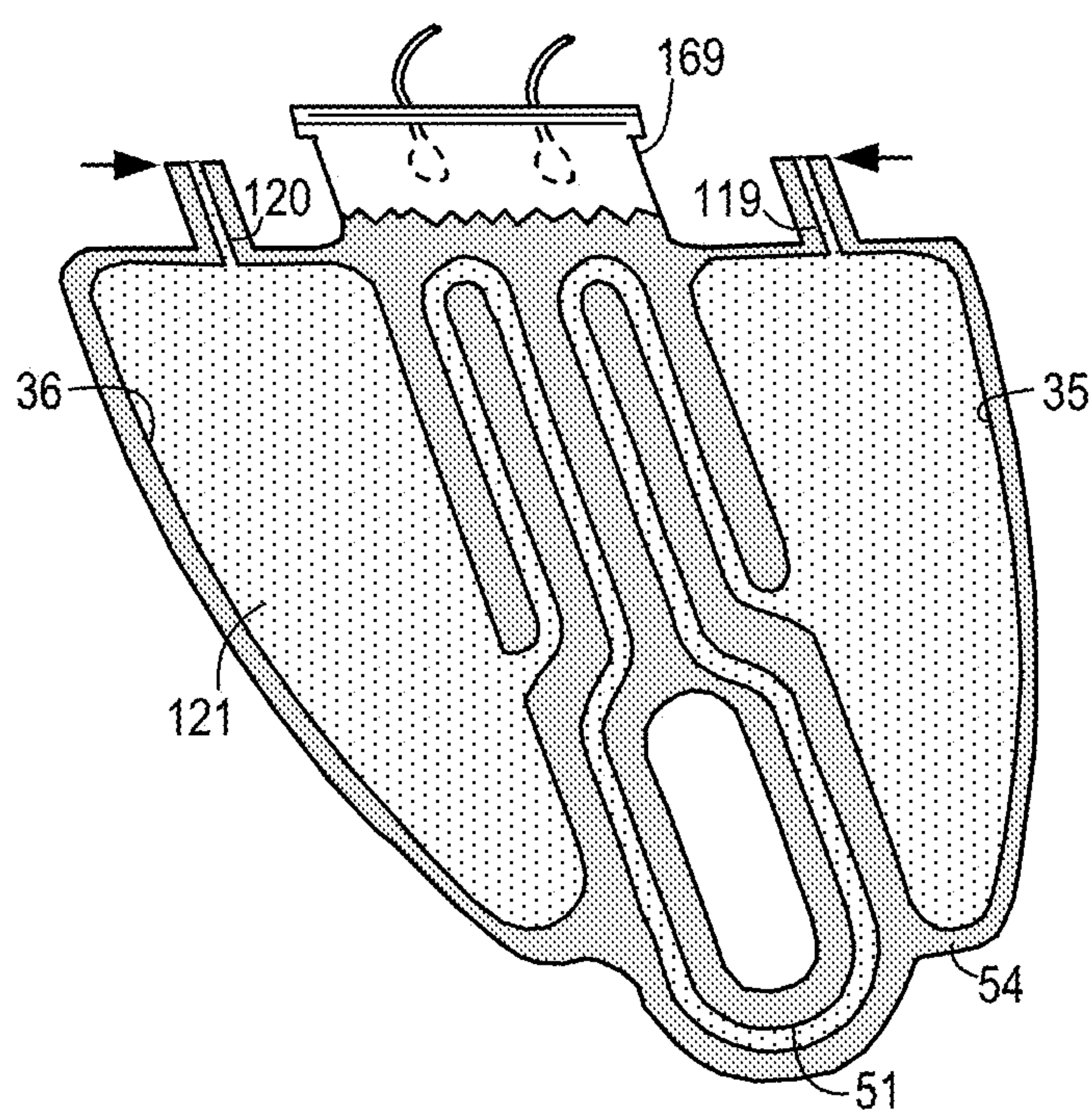


FIG. 10C

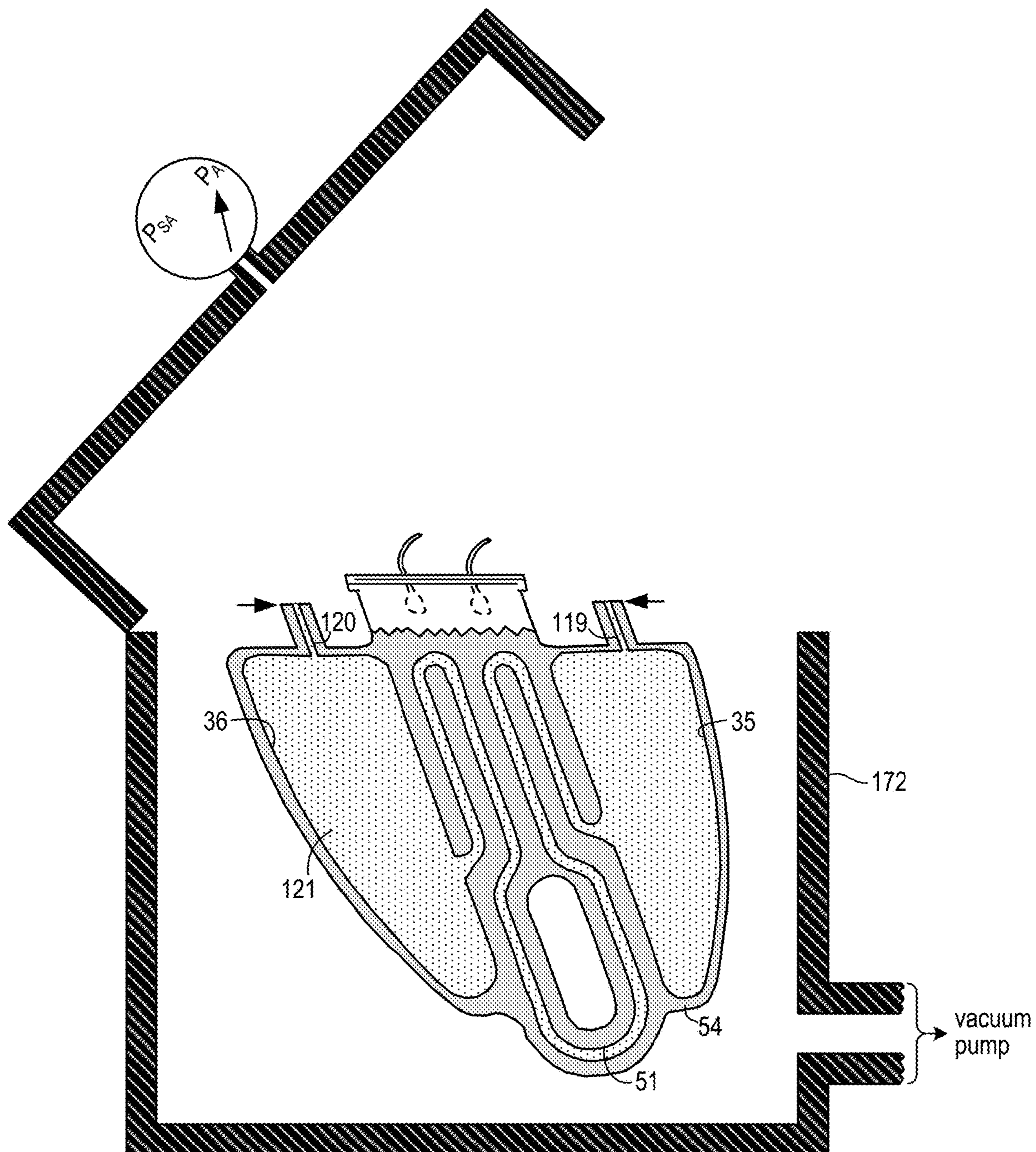


FIG. 10D

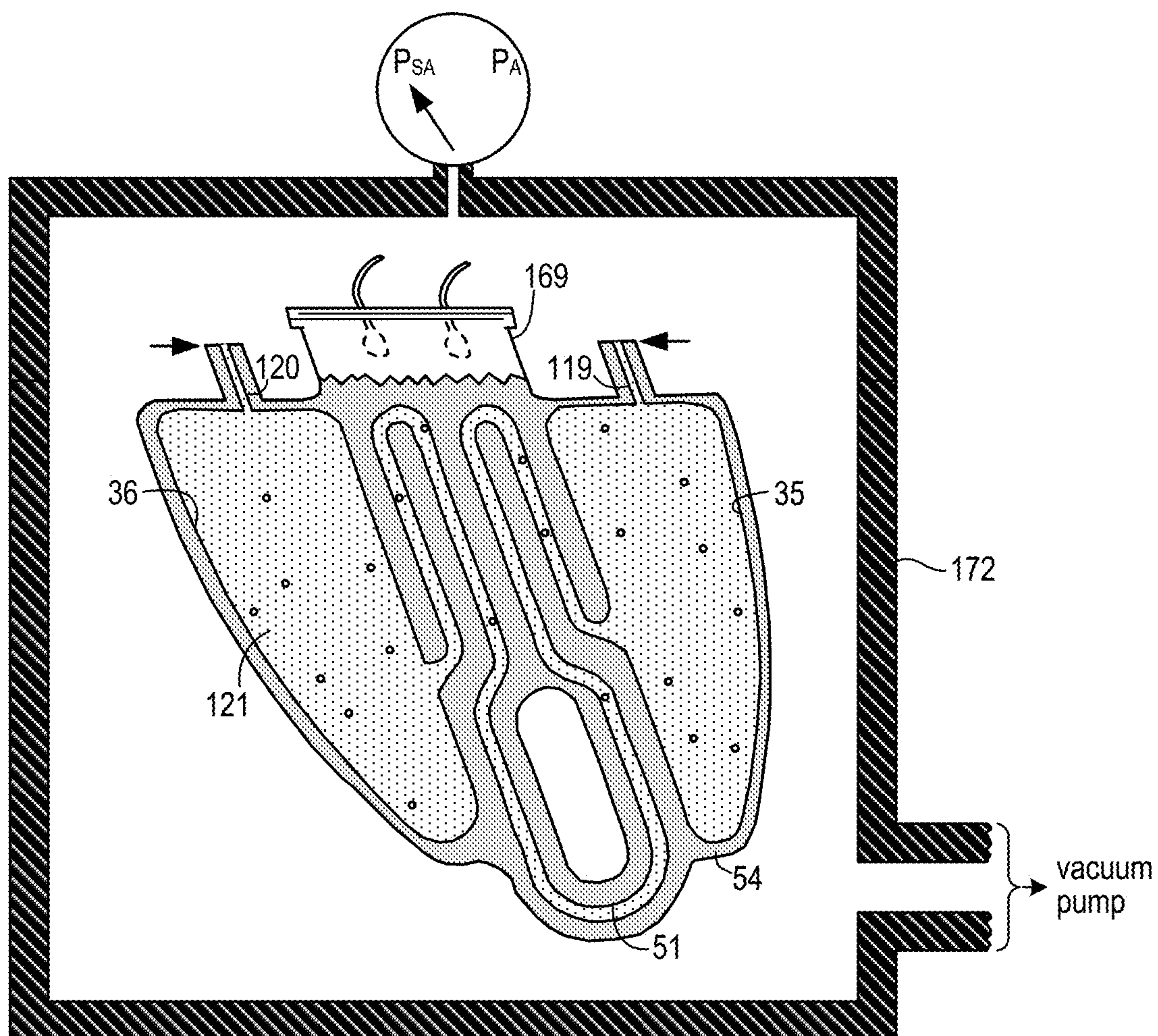


FIG. 10E



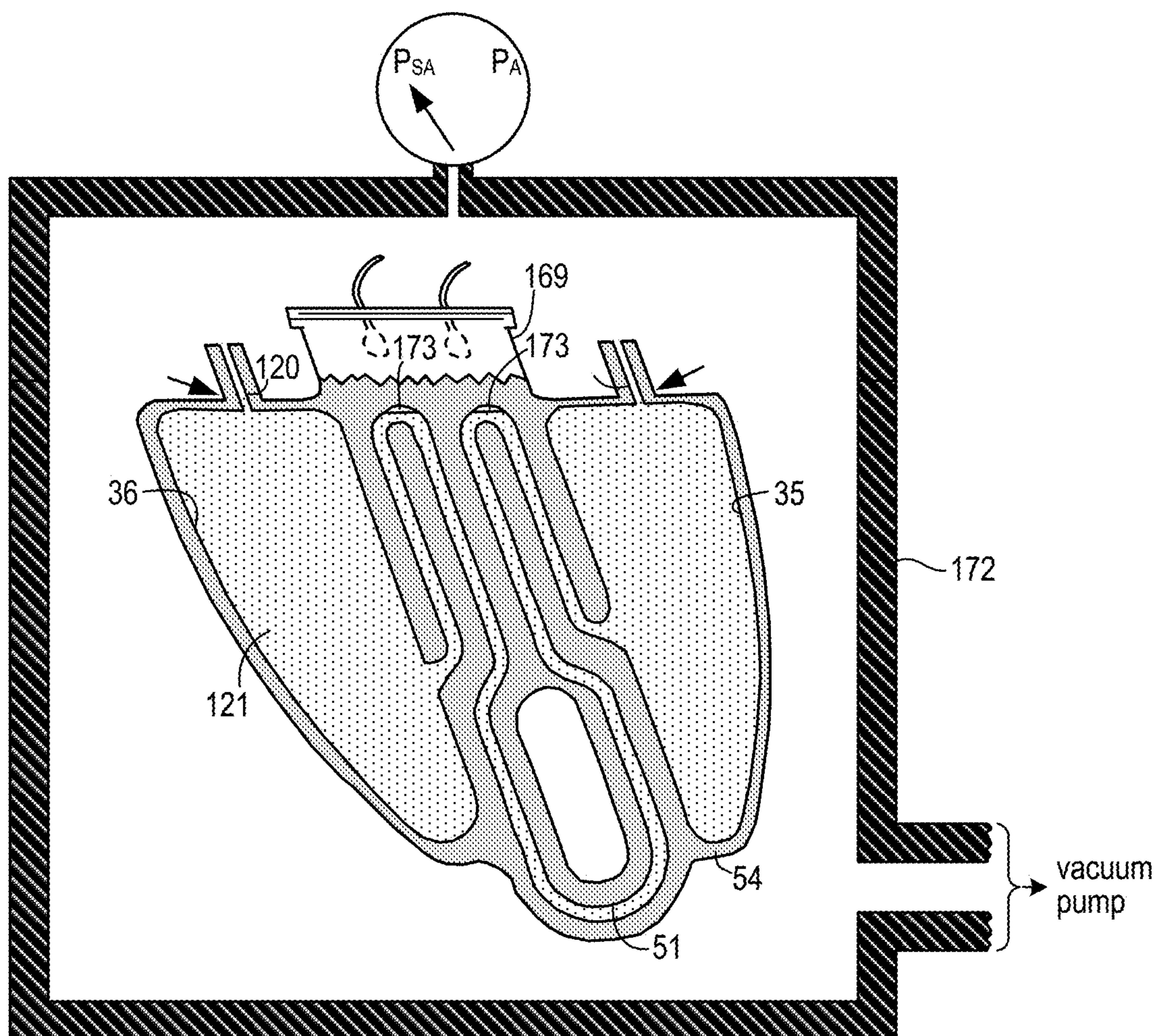


FIG. 10F

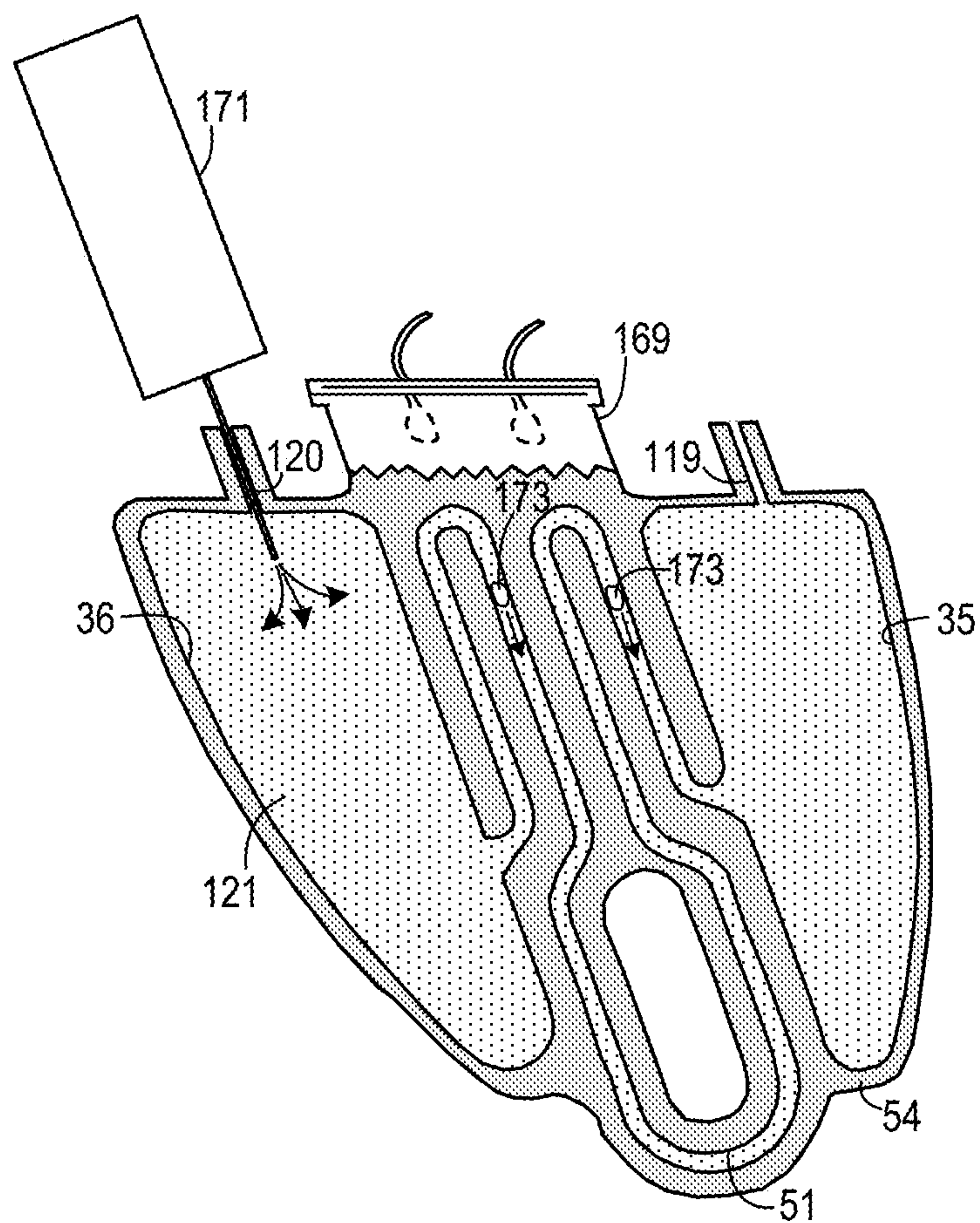


FIG. 10G

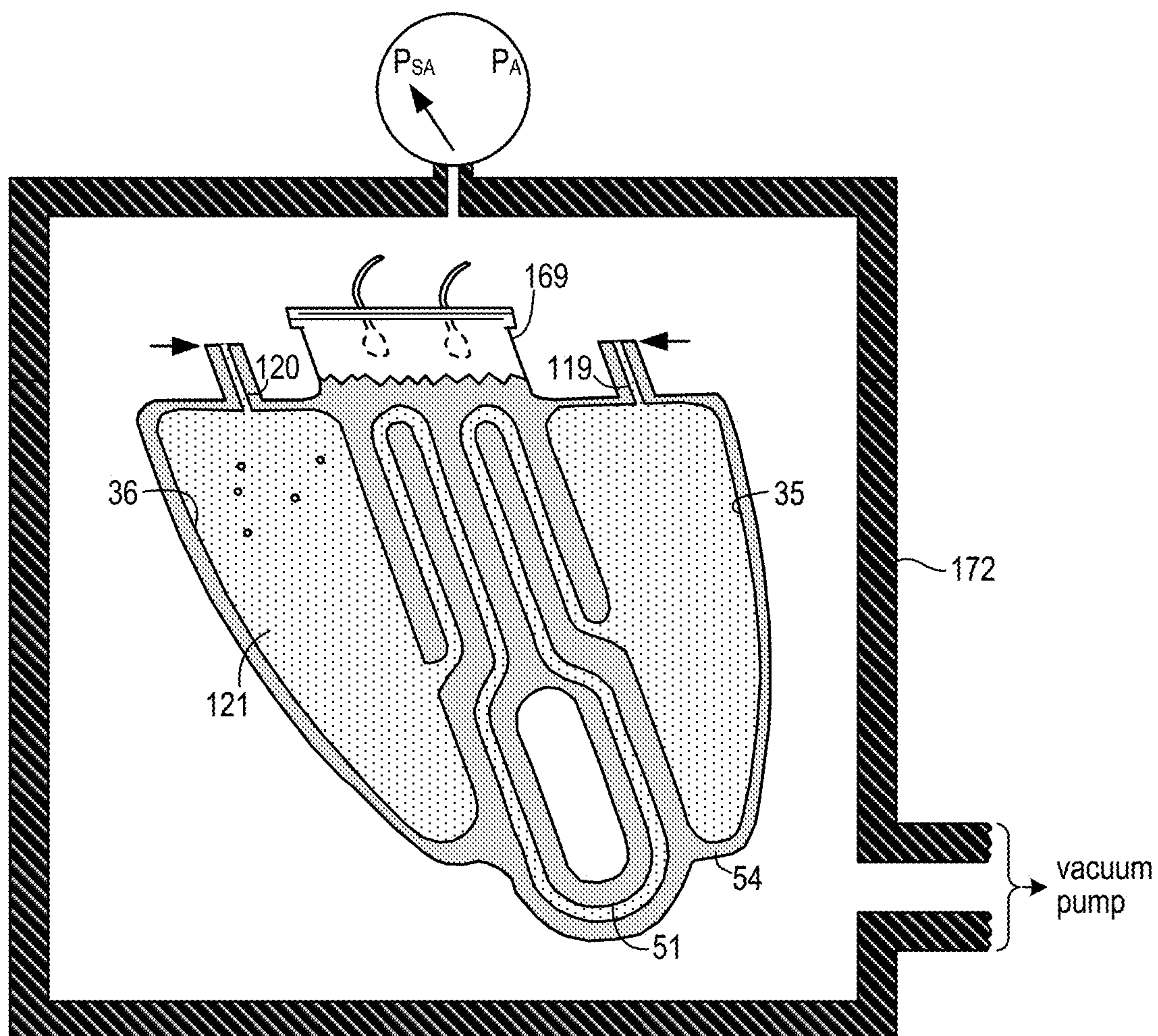


FIG. 10H



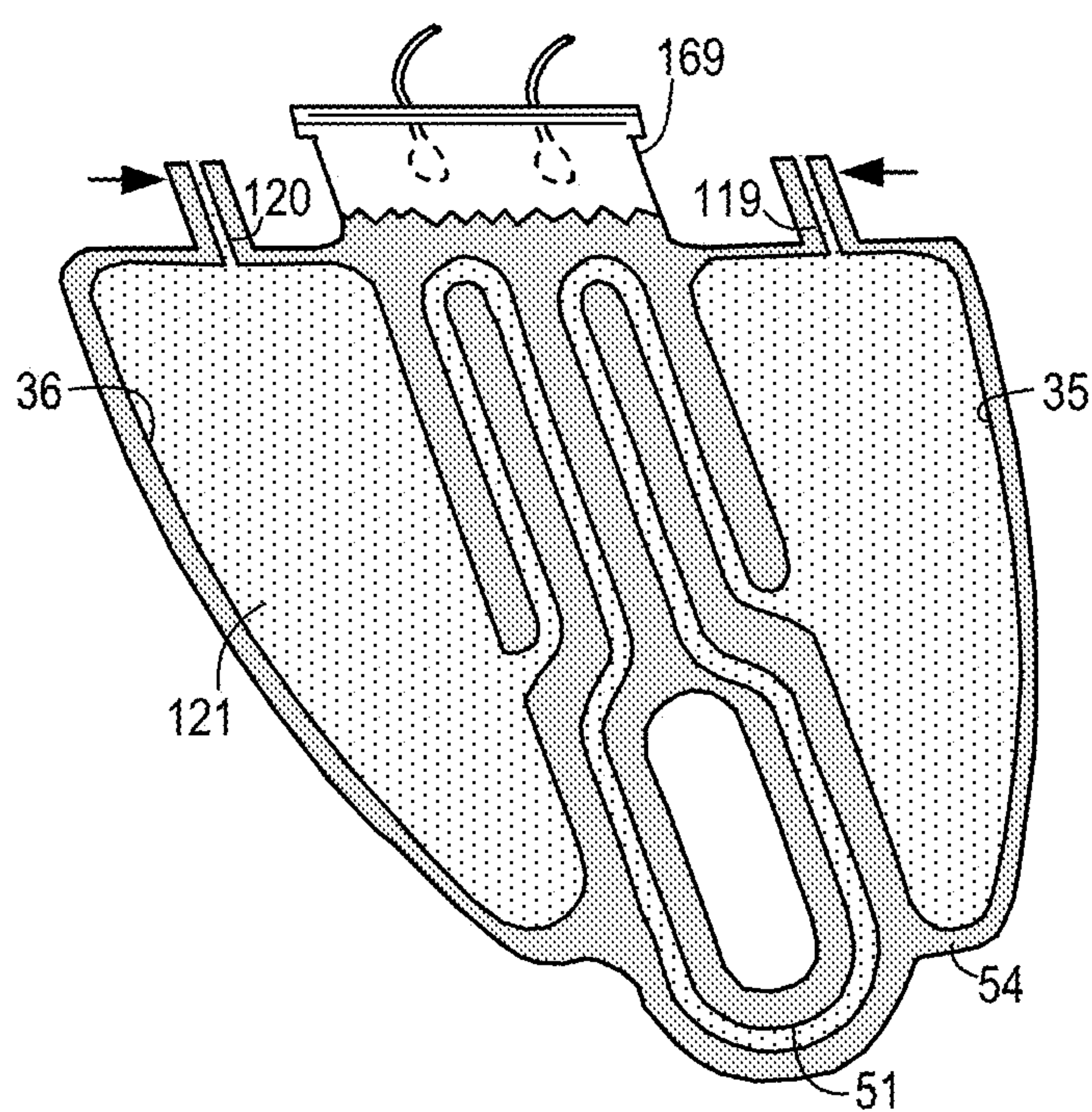


FIG. 10I

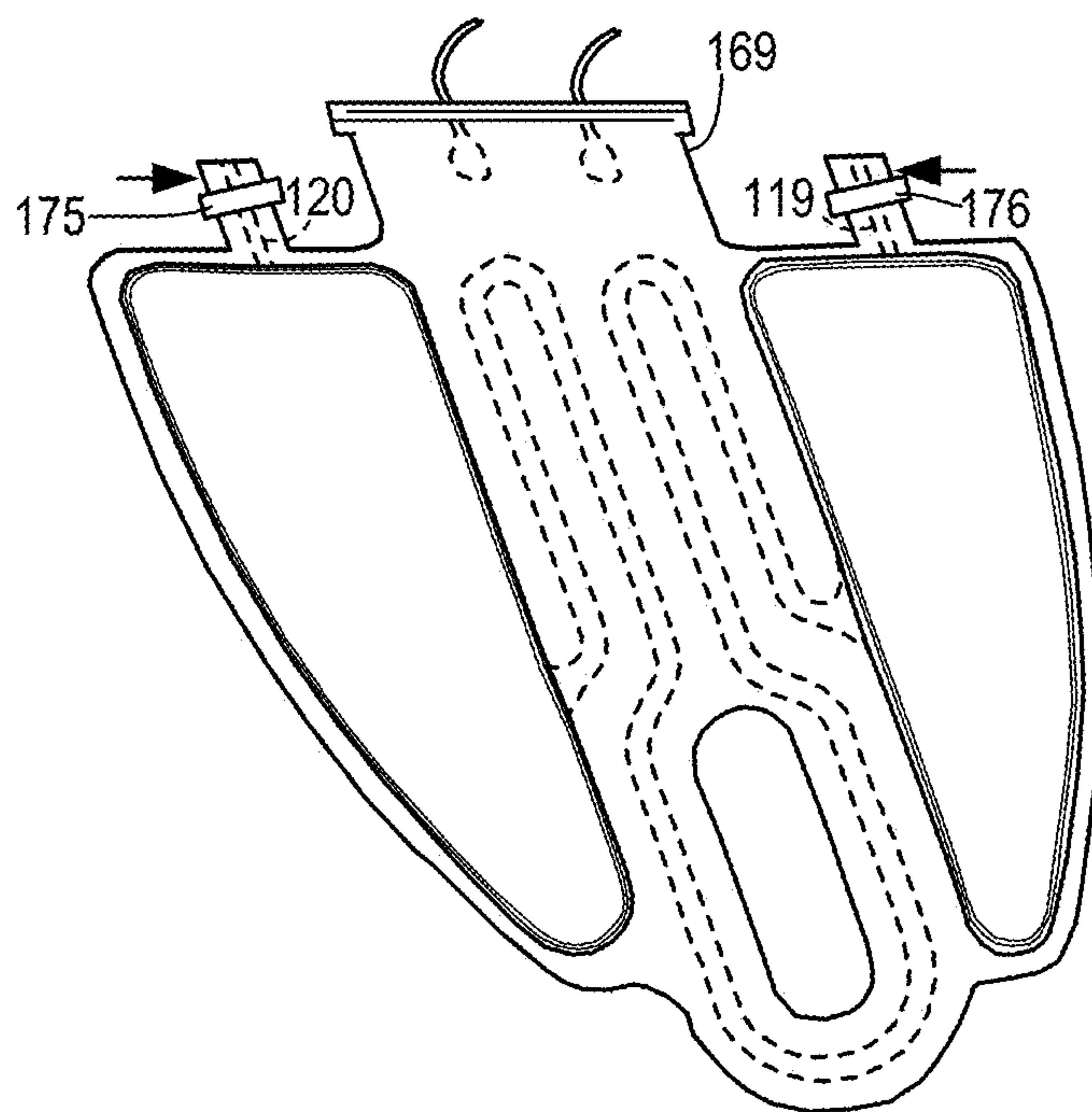


FIG. 10J

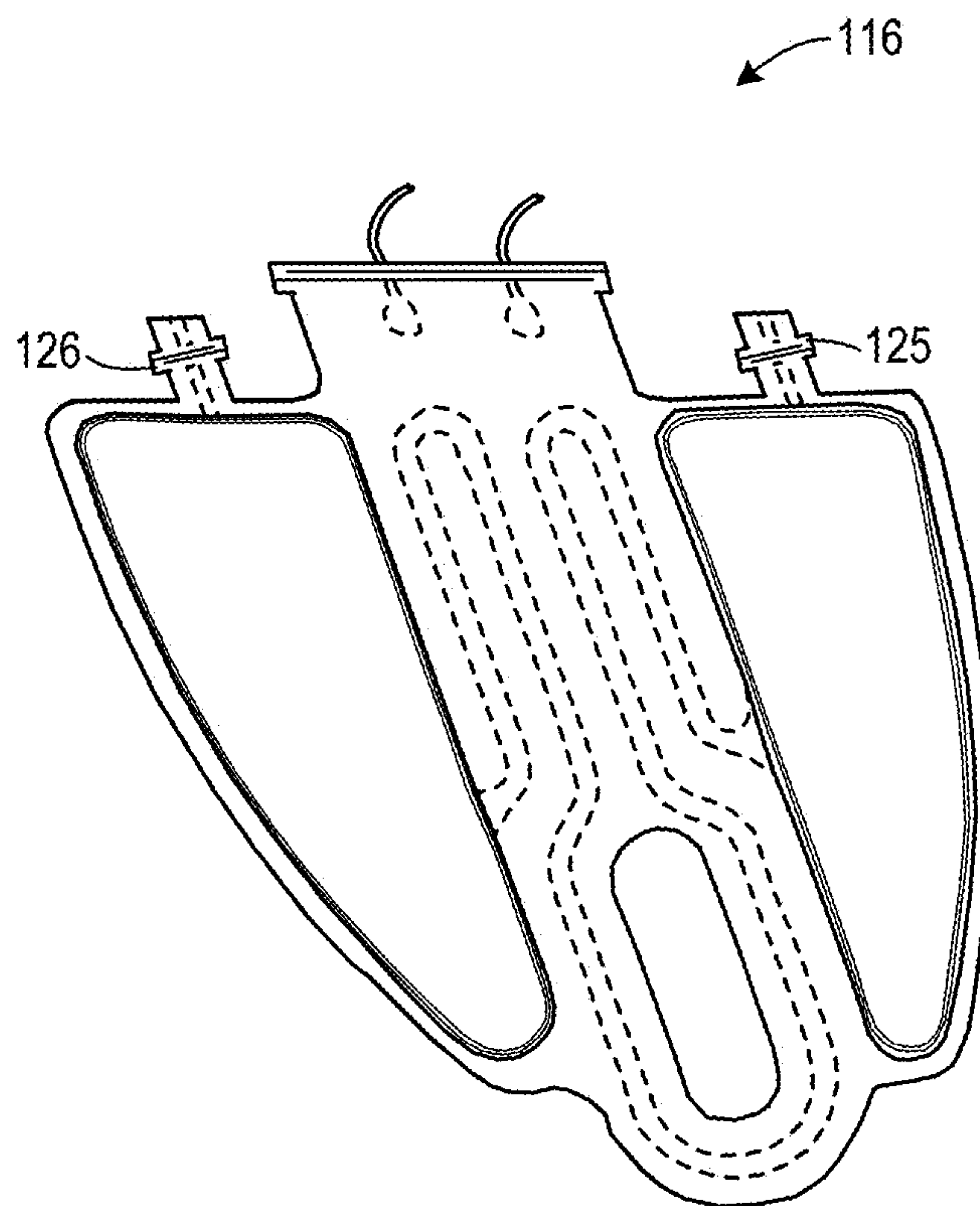


FIG. 10K



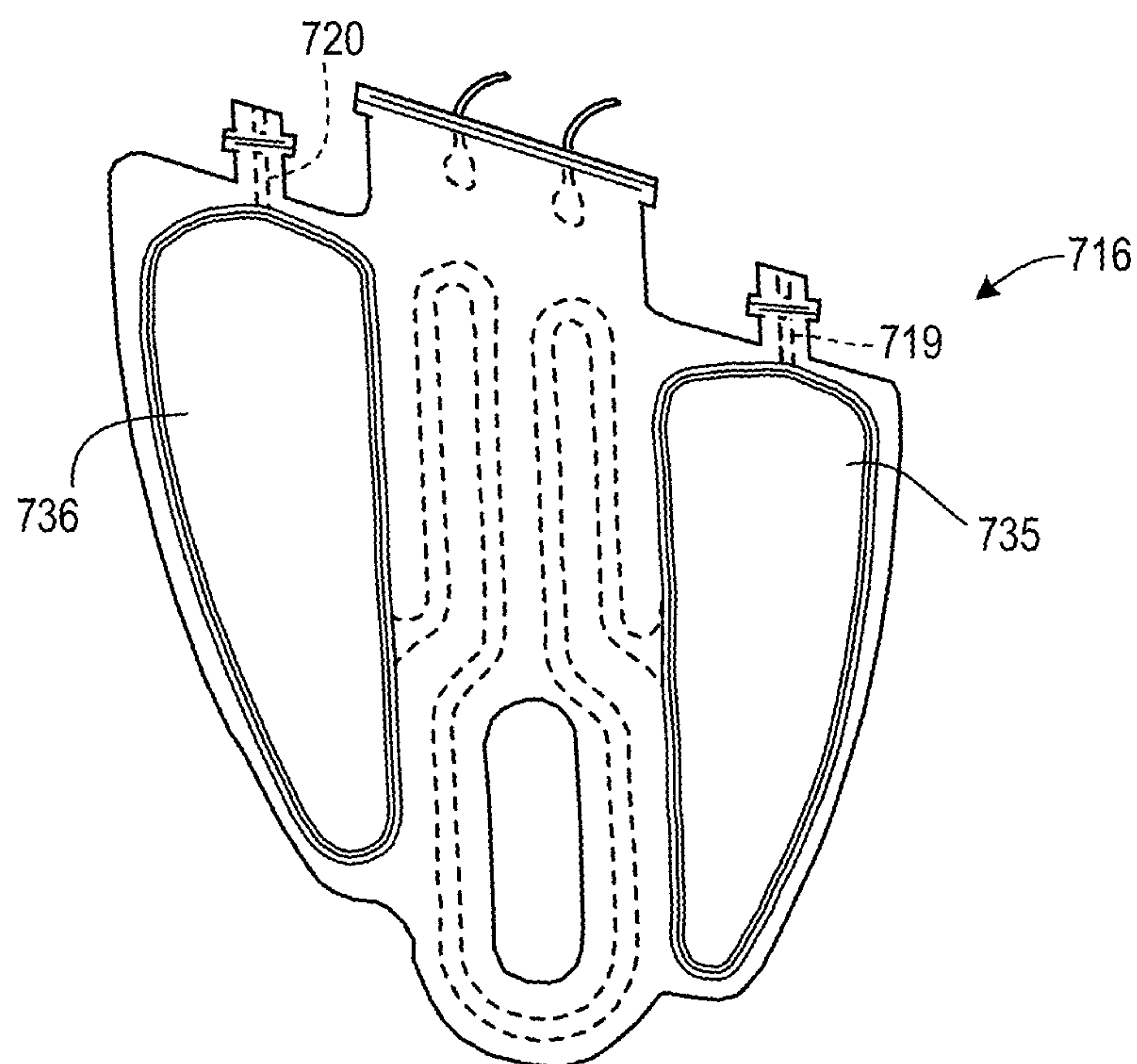


FIG. 11A

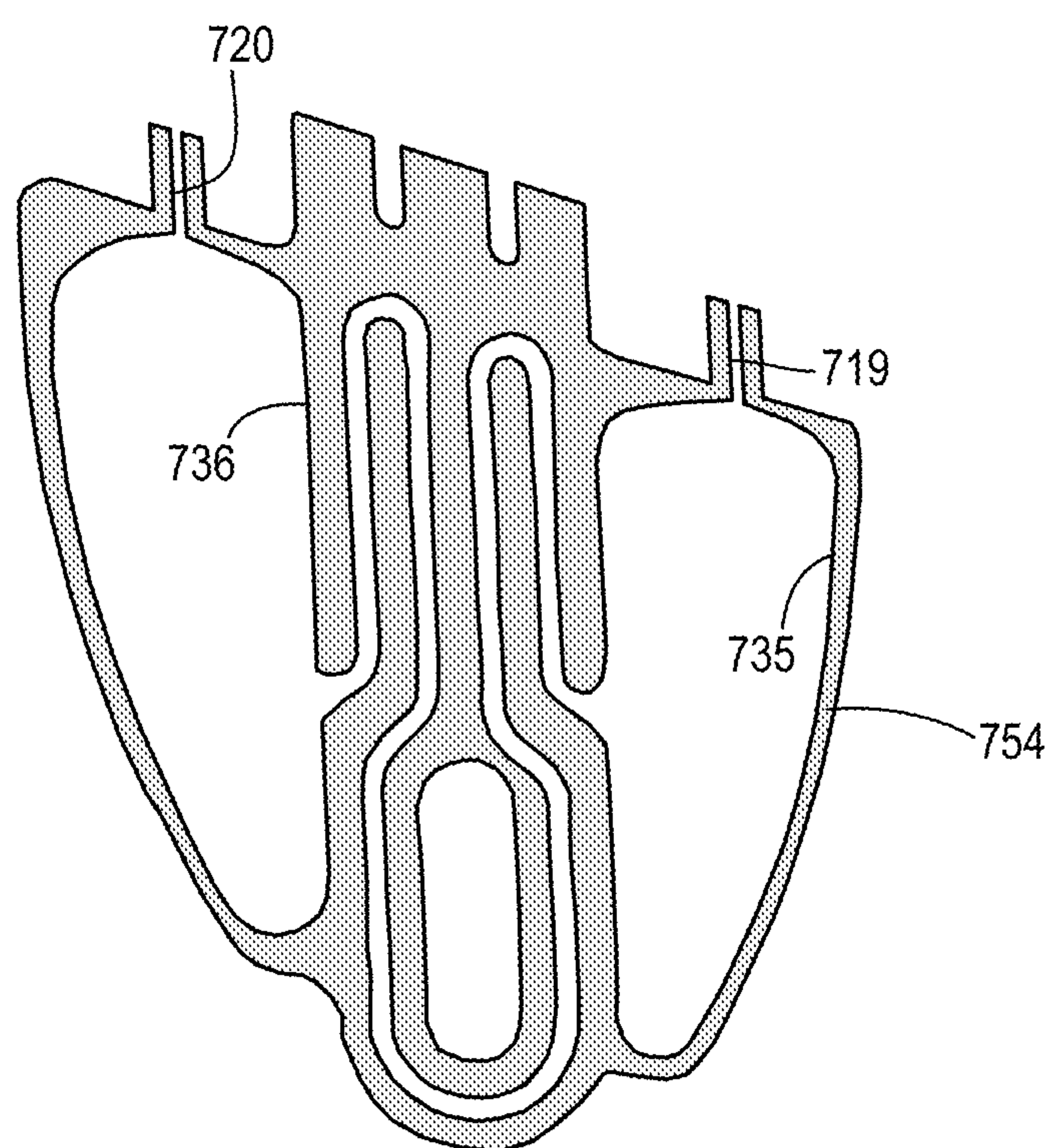


FIG. 11B

## 1

# METHOD OF FILLING ELECTRORHEOLOGICAL FLUID STRUCTURE

## CROSS REFERENCE TO RELATED APPLICATION

This application claims priority to U.S. provisional patent application No. 62/260,897, titled "METHOD OF FILLING ELECTRORHEOLOGICAL FLUID STRUCTURE" and filed Nov. 30, 2015. Application No. 62/260,897, in its entirety, is incorporated by reference herein.

## BACKGROUND

Conventional articles of footwear generally include an upper and a sole structure. The upper provides a covering for the foot and securely positions the foot relative to the sole structure. The sole structure is secured to a lower portion of the upper and is configured so as to be positioned between the foot and the ground when a wearer is standing, walking, or running.

Conventional footwear is often designed with the goal of optimizing a shoe for a particular condition or set of conditions. For example, sports such as tennis and basketball require substantial side-to-side movements. Shoes designed for wear while playing such sports often include substantial reinforcement and/or support in regions that experience more force during sideways movements. As another example, running shoes are often designed for forward movement by a wearer in a straight line. Difficulties can arise when a shoe must be worn during changing conditions, or during multiple different types of movements.

## SUMMARY

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the invention.

In at least some embodiments, a method of filling an electrorheological fluid structure may include introducing electrorheological fluid into an interior volume of a housing. The electrorheological fluid within the housing may then be subjected to a sub-atmospheric pressure. Subsequently, the interior volume may be sealed relative to an exterior of the housing.

Additional embodiments are described herein.

## BRIEF DESCRIPTION OF THE DRAWINGS

Some embodiments are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings and in which like reference numerals refer to similar elements.

FIG. 1 is a medial side view of a shoe according to some embodiments.

FIG. 2A is a bottom view of the sole structure of the shoe of FIG. 1.

FIG. 2B is a bottom view of the sole structure of the shoe of FIG. 1, but with a forefoot outsole element and an incline adjuster removed.

FIG. 2C is a bottom view of the forefoot outsole element of the sole structure of the shoe of FIG. 1.

FIG. 3 is a partially exploded medial perspective view of the sole structure of the shoe of FIG. 1.

## 2

FIG. 4A is an enlarged top view of an incline adjuster of the shoe of FIG. 1.

FIG. 4B is a rear edge view of the incline adjuster of FIG. 4A.

FIG. 5A is a top view of a bottom layer of the incline adjuster of FIG. 4A.

FIG. 5B is a top view of a middle layer of the incline adjuster of FIG. 4A.

FIG. 5C1 is a top view of a top layer of the incline adjuster of FIG. 4A.

FIG. 5C2 is a bottom view of the top layer of the incline adjuster of FIG. 4A.

FIG. 5C3 is a partial area cross-sectional view of the top layer of the incline adjuster of FIG. 4A.

FIG. 5D1 shows a first assembly operation in the fabrication of an incline adjuster according to some embodiments.

FIG. 5D2 shows a second assembly operation in the fabrication of an incline adjuster according to some embodiments.

FIG. 5D3 is a top view of a partially completed incline adjuster after bonding of layers but prior to filling with electrorheological fluid.

FIG. 6 is a block diagram showing electrical system components in the shoe of FIG. 1.

FIGS. 7A through 7D are partially schematic area cross-sectional diagrams showing operation of the incline adjuster of the shoe of FIG. 1 when going from a minimum incline condition to a maximum incline condition.

FIG. 7E is a top view of the incline adjuster and a bottom plate of the shoe of FIG. 1, and showing the approximate locations of sectioning lines corresponding to the views of FIGS. 7A-7D.

FIGS. 8A and 8B are top views of two sides of a first RF welding tool according to some embodiments.

FIGS. 8C and 8D are top views of two sides of a second RF welding tool according to some embodiments.

FIG. 9 is a block diagram showing steps in a method according to some embodiments.

FIGS. 10A through 10K are partially schematic drawings showing various operations during a method according to FIG. 9.

FIG. 11A is a top view of an incline adjuster according to another embodiment.

FIG. 11B is a top view of a middle layer of the incline adjuster of FIG. 11A.

## DETAILED DESCRIPTION

In various types of activities, it may be advantageous to change the shape of a shoe or shoe portion while a wearer of that shoe is running or otherwise participating in the activity. In many running competitions, for example, athletes race around a track having curved portions, also known as "bends." In some cases, particularly shorter events such as 200 meter or 400 meter races, athletes may be running at sprint paces on a track bend. Running on a flat curve at a fast pace is biomechanically inefficient, however, and may require awkward body movements. To counteract such effects, bends of some running tracks are banked. This banking allows more efficient body movement and typically results in faster running times. Tests have shown that similar advantages can be achieved by altering the shape of a shoe. In particular, running on a flat track bend in a shoe having a footbed that is inclined relative to the ground can mimic the benefits of running on a banked bend in a shoe having a non-inclined footbed. However, an inclined footbed is a



disadvantage on straight portions of a running track. Footwear that can provide an inclined footbed when running on a bend and reduce or eliminate the incline when running on a straight track section would offer a significant advantage.

In footwear according to some embodiments, electrorheological (ER) fluid is used to change the shape of one or more shoe portions. ER fluids typically comprise a non-conducting oil or other fluid in which very small particles are suspended. In some types of ER fluid, the particles may be have diameters of 5 microns or less and may be formed from polystyrene or another polymer having a dipolar molecule. When an electric field is imposed across the ER fluid, the viscosity of the fluid increases as the strength of that field increases. As described in more detail below, this effect can be used to control transfer of fluid and modify the shape of a footwear component. Although track shoe embodiments are initially described, other embodiments include footwear intended for other sports or activities.

To assist and clarify subsequent description of various embodiments, various terms are defined herein. Unless context indicates otherwise, the following definitions apply throughout this specification (including the claims). “Shoe” and “article of footwear” are used interchangeably to refer to an article intended for wear on a human foot. A shoe may or may not enclose the entire foot of a wearer. For example, a shoe could include a sandal-like upper that exposes large portions of a wearing foot. The “interior” of a shoe refers to space that is occupied by a wearer’s foot when the shoe is worn. An interior side, surface, face, or other aspect of a shoe component refers to a side, surface, face or other aspect of that component that is (or will be) oriented toward the shoe interior in a completed shoe. An exterior side, surface, face or other aspect of a component refers to a side, surface, face or other aspect of that component that is (or will be) oriented away from the shoe interior in the completed shoe. In some cases, the interior side, surface, face or other aspect of a component may have other elements between that interior side, surface, face or other aspect and the interior in the completed shoe. Similarly, an exterior side, surface, face or other aspect of a component may have other elements between that exterior side, surface, face or other aspect and the space external to the completed shoe.

Shoe elements can be described based on regions and/or anatomical structures of a human foot wearing that shoe, and by assuming that the interior of the shoe generally conforms to and is otherwise properly sized for the wearing foot. A forefoot region of a foot includes the heads and bodies of the metatarsals, as well as the phalanges. A forefoot element of a shoe is an element having one or more portions located under, over, to the lateral and/or medial side of, and/or in front of a wearer’s forefoot (or portion thereof) when the shoe is worn. A midfoot region of a foot includes the cuboid, navicular, and cuneiforms, as well as the bases of the metatarsals. A midfoot element of a shoe is an element having one or more portions located under, over, and/or to the lateral and/or medial side of a wearer’s midfoot (or portion thereof) when the shoe is worn. A heel region of a foot includes the talus and the calcaneus. A heel element of a shoe is an element having one or more portions located under, to the lateral and/or medial side of, and/or behind a wearer’s heel (or portion thereof) when the shoe is worn. The forefoot region may overlap with the midfoot region, as may the midfoot and heel regions.

Unless indicated otherwise, a longitudinal axis refers to a horizontal heel-toe axis along the center of the foot that is roughly parallel to a line along the second metatarsal and second phalanges. A transverse axis refers to a horizontal

axis across the foot that is generally perpendicular to a longitudinal axis. A longitudinal direction is generally parallel to a longitudinal axis. A transverse direction is generally parallel to a transverse axis.

FIG. 1 is a medial side view of a track shoe 10 according to some embodiments. The lateral side of shoe 10 has a similar configuration and appearance, but is configured to correspond to a lateral side of a wearer foot. Shoe 10 is configured for wear on a right foot and is part of a pair that includes a shoe (not shown) that is a mirror image of shoe 10 and is configured for wear on a left foot.

Shoe 10 includes an upper 11 attached to a sole structure 12. Upper 11 may be formed from any of various types or materials and have any of a variety of different constructions. In some embodiments, for example, upper 11 may be knitted as a single unit and may not include a bootie of other type of liner. In some embodiments, upper 11 may be slip lasted by stitching bottom edges of upper 11 to enclose a foot-receiving interior space. In other embodiments, upper 11 may be lasted with a strobel or in some other manner. A battery assembly 13 is located in a rear heel region of upper 11 and includes a battery that provides electrical power to a controller. The controller is not visible in FIG. 1, but is described below in connection with other drawing figures.

Sole structure 12 includes a footbed 14, an outsole 15, and an incline adjuster 16. Incline adjuster 16 is situated between outsole 15 and footbed 14 in a forefoot region. As explained in more detail below, incline adjuster 16 includes a medial side fluid chamber that supports a medial forefoot portion of footbed 14, as well as a lateral side fluid chamber that supports a lateral forefoot portion of footbed 14. ER fluid may be transferred between those chambers through a connecting transfer channel that is in fluid communication with the interiors of both chambers. That fluid transfer may raise the height of one chamber relative to the other chamber, resulting in an incline in a portion of footbed 14 located over the chambers. When further flow of ER fluid through the channel is interrupted, the incline is maintained until ER fluid flow is allowed to resume.

Outsole 15 forms the ground-contacting portion of sole structure 12. In the embodiment of shoe 10, outsole 15 includes a forward outsole section 17 and a rear outsole section 18. The relationship of forward outsole section 17 and rear outsole section 18 can be seen by comparing FIG. 2A, a bottom view of sole structure 12, and FIG. 2B, a bottom view of sole structure 12 with forefoot outsole section 17 and incline adjuster 16 removed. FIG. 2C is a bottom view of forefoot outsole section 17 removed from sole structure 12. As seen in FIG. 2A, forward outsole section 17 extends through forefoot and central midfoot regions of sole structure 12 and tapers to a narrowed end 19. End 19 is attached to rear outsole section 18 at a joint 20 located in the heel region. Rear outsole section 18 extends over side midfoot regions and over the heel region and is attached to footbed 14. Forward outsole section 17 is also coupled to footbed 14 by a fulcrum element and by the above-mentioned fluid chambers of incline adjuster 16. Forefoot outsole section 17 pivots about a longitudinal axis L1 passing through joint 20 and through the forefoot fulcrum element. In particular, and as explained below, forefoot outsole section 17 rotates about axis L1 as a forefoot portion of footbed 14 inclines relative to forefoot outsole section 17.

Outsole 15 may be formed of a polymer or polymer composite and may include rubber and/or other abrasion-resistant material on ground-contacting surfaces. Traction elements 21 may be molded into or otherwise formed in the bottom of outsole 15. Forefoot outsole section 17 may also



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include receptacles to hold one or more removable spike elements 22. In other embodiments, outsole 15 may have a different configuration.

Footbed 14 includes a midsole 25. In the embodiment of shoe 10, midsole 25 has a size and a shape approximately corresponding to a human foot outline, is a single piece that extends the full length and width of footbed 14, and includes a contoured top surface 26 (shown in FIG. 3). The contour of top surface 26 is configured to generally correspond to the shape of the plantar region of a human foot and to provide arch support. Midsole 25 may be formed from ethylene vinyl acetate (EVA) and/or one or more other closed cell polymer foam materials. Midsole 25 may also have pockets 27 and 28 formed therein to house a controller and other electronic components, as described below. Upwardly extending medial and lateral sides of rear outsole section 18 may also provide additional medial and lateral side support to a wearer foot. In other embodiments, a footbed may have a different configuration, e.g., a midsole may cover less than all of a footbed or may be entirely absent, and/or a footbed may include other components.

FIG. 3 is a partially exploded medial perspective view of sole structure 12. Bottom support plate 29 is located in a plantar region of shoe 10. In the embodiment of shoe 10, bottom support plate 29 is attached to a top surface 30 of forward outsole section 17. Bottom support plate 29, which may be formed from a relatively stiff polymer or polymer composite, helps to stiffen the forefoot region of forward outsole section 17 and provide a stable base for incline adjuster 16. A medial force-sensing resistor (FSR) 31 and a lateral FSR 32 are attached to a top surface 33 of bottom support plate 29. As explained below, FSRs 31 and 32 provide outputs that help determine pressures within chambers of incline adjuster 16.

Fulcrum element 34 is attached to top surface 33 of lower support plate 29. Fulcrum element 34 is positioned between FSRs 31 and 32 in a front portion of bottom support plate 29. Fulcrum element 34 may be formed from polyurethane, silicon rubber, EVA, or from one or more other materials that are generally incompressible under loads that result when a wearer of shoe 10 runs. Fulcrum element 34 provides resistance to transverse and longitudinal forces applied to the incline adjuster 16.

Incline adjuster 16 is attached to top surface 33 of lower support plate 29. A medial fluid chamber 35 of incline adjuster 16 is positioned over medial FSR 31. A lateral fluid chamber 36 of incline adjuster 16 is positioned over lateral FSR 32. Incline adjuster 16 includes an aperture 37 through which fulcrum element 34 extends. At least a portion of fulcrum element 34 is positioned between chambers 35 and 36. Additional details of incline adjuster 16 are discussed in connection with subsequent drawing figures. A top support plate 41 is also located in a plantar region of shoe 10 and is positioned over incline adjuster 16. In the embodiment of shoe 10, top support plate 41 is generally aligned with bottom support plate 29. Top support plate 41, which may also be formed from a relatively stiff polymer or polymer composite, provides a stable and relatively non-deformable region against which incline adjuster 16 may push, and which supports the forefoot region of footbed 14.

A forefoot region portion of the midsole 25 underside is attached to the top surface 42 of top support plate 41. Portions of the midsole 25 underside in the heel and side midfoot regions are attached to a top surface 43 of rear outsole section 18. End 19 of forward outsole section 17 is attached to rear outsole section 18 behind the rear-most location 44 of the front edge of section 18 so as to form joint

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20. In some embodiments, end 19 may be a tab that slides into a slot formed in section 18 at or near location 44, and/or may be wedged between top surface 43 and the underside of midsole 25.

Also shown in FIG. 3 are a DC-to-high-voltage-DC converter 45 and a printed circuit board (PCB) 46 of a controller 47. Converter 45 converts a low voltage DC electrical signal into a high voltage (e.g., 5000V) DC signal that is applied to electrodes within incline adjuster 16. PCB 46 includes one or more processors, memory and other components and is configured to control incline adjuster 16 through converter 45. PCB 46 also receives inputs from FSRs 31 and 32 and receives electrical power from battery unit 13. PCB 46 and converter 45 may be attached to the top surface of forward outsole section 17 in a midfoot region 48, and may also rest within pockets 28 and 27, respectively, in the underside midsole 25. Wires 23a and 24a electrically connect converter 45 to incline adjuster 16. A terminal 23b on a first end of wire 23a is inserted into a connection passage 39 on the rear edge of incline adjuster 16 and attached to a portion of a conductive trace projecting into an access passage 39, as described in more detail below. A terminal 24b on a first end of wire 24a is inserted into an access passage 40 on the rear edge of incline adjuster 16 and attached to a portion of a separate conductive trace projecting into passage 40, as described in more detail below. In some embodiments, terminals 23b and 24b may simply be portions of conductors of wires 23a and 23b that have been exposed by removing insulating jacket material. In other embodiments, separate terminal structures may be added. Second ends of wires 23a and 24a are connected to appropriate terminals of converter 45. Additional sets of wires, not shown, connect converter 45 and PCB 46 and connect PCB 46 to battery assembly 13.

FIG. 4A is an enlarged top view of incline adjuster 16 and attached wires 23a and 24a. FIG. 4B is a rear edge view of incline adjuster 16 from the location indicated in FIG. 4A. Medial fluid chamber 35 is in fluid communication with lateral fluid chamber 36 through a fluid transfer channel 51. An ER fluid fills chambers 35 and 36 and transfer channel 51. One example of an ER fluid that may be used in some embodiments is sold under the name "RheOil 4.0" by Fludicon GmbH, Landwehrstrasse 55, 64293 Darmstadt, Deutschland (Germany). In the present example, it is assumed that the top of incline adjuster 16 is formed by an opaque layer, and thus transfer channel 51 is indicated in FIG. 4A with broken lines. In some embodiments, the top and/or other layers of an incline adjuster may be transparent or translucent.

Access passages 39 and 40 are similarly indicated in FIG. 4A with broken lines. Terminals 23b and 24b have been inserted into passages 39 and 40 and welded in place, as described in more detail below. As a result of that welding, a rear portion of incline adjuster 16 around passages 39 and 40 has been flattened to form a crimp 151. Within crimp 151, layer 54 has melted and sealed around the outer surfaces of wires 23a and 23b. In at least some embodiments, wires 23a and 24a are attached to incline adjuster 16 prior to filling with ER fluid.

Transfer channel 51 has a serpentine shape so as to provide increased surface area for electrodes within channel 51 to create an electrical field in fluid within channel 51. For example, and as seen in FIG. 4A, channel 51 includes three 180° curved sections joining other sections of channel 51 that cover the space between chambers 35 and 36. In some embodiments, transfer channel 51 may have a maximum



height *h* (FIG. 4B) of 1 millimeter (mm), an average width (*w*) of 2 mm, and a minimum length along the flow direction of at least 257 mm.

In some embodiments, height of the transfer channel may practically be limited to a range of at least 0.250 mm to not more than 3.3 mm. An incline adjuster constructed of pliable material may be able to bend with the shoe during use. Bending across the transfer channel locally decreases the height at the point of bending. If sufficient allowance is not made, the corresponding increase in electric field strength may exceed the maximum dielectric strength of the ER fluid, causing the electric field to collapse. In the extreme, electrodes could become so close so as to actually touch, with the same resultant electric field collapse.

The viscosity of ER fluid increases with the applied electric field strength. The effect is non-linear and the optimum field strength is in the range of 3 to 6 kilovolts per millimeter (kV/mm). The high-voltage dc-dc converter used to boost the 3 to 5 V of the battery may be limited by physical size and safety considerations to less than 2 W or a maximum output voltage of less than or equal to 10 kV. To keep the electric field strength within the desired range, the height of the transfer channel may therefore be limited in some embodiments to a maximum of about 3.3 mm (10 kV/3 kV/mm).

The width of the transfer channel may be practically limited to a range of at least 0.5 mm to not more than 4 mm. As explained below, an incline adjuster may be constructed of 3 or more layers of thermal plastic urethane film. The layers of film may be bonded together with heat and pressure. During this bonding process, temperatures in portions of the materials may exceed the glass transition temperature when melting so as to bond melted materials of adjoining layers. The pressure during bonding inter-mixes the melted material, but may also extrude a portion of the melted material into the transfer channel preformed within the middle spacer layer of the incline adjuster. The channel may thus be partially filled by this material. At channel widths less than 0.5 mm, the proportion of the material extruded may be a large percentage of the channel width, thereby restricting flow of the ER fluid.

The maximum width of the channel may be limited by the physical space between the two chambers of the incline adjuster. If the channel is wide, the material within the middle layer may become thin and unsupported during construction, and walls of the channel may be easily dislodged. The equivalent series resistance of ER fluid will also decrease as channel width increases, which increases the power consumption. For a shoe size range down to M5.5 (US) the practical width may be limited to less than 4 mm.

The desired length of the transfer channel may be a function of the maximum pressure difference between chambers of the incline adjuster when in use. The longer the channel, the greater the pressure difference that can be withstood. Optimum channel length may be application dependent and construction dependent and therefore may vary among different embodiments. A detriment of a long transfer channel is a greater restriction to fluid flow when the electric field is removed. In some embodiments, practical limits of channel length are in the range of 25 mm to 350 mm.

Incline adjuster 16 includes a medial side fill tab 117 and a lateral side fill tab 118. Tabs 117 and 118 respectively include fill channels 119 and 120. After certain components of incline adjuster 116 have been assembled and bonded, and as described below in further detail, ER fluid may be injected into chambers 35 and 36 and into transfer channel

51 through channel 119 and/or through channel 120. Crimps 125 and 126 may subsequently be formed to close and seal channels 119 and 120.

In some embodiments, an incline adjuster may have a polymeric housing. As seen in FIG. 4B, the polymeric housing of incline adjuster 16 may include a bottom layer 53, a middle/spacer layer 54, and a top layer 55. Bottom layer 53 forms the bottoms of chambers 35 and 36, the bottom of transfer channel 51, the bottoms of access passages 39 and 40, and the bottoms of fill channels 119 and 120. Middle/spacer layer 54 includes open spaces that form the side walls of chambers 35 and 36, the side walls of transfer channel 51, the side walls of fill channels 119 and 120, and the side walls of passages 39 and 40. Top layer 55 includes two pockets. A medial side pocket 57 forms the top and upper sidewalls of medial chamber 35. A lateral side pocket 58 forms the top and upper sidewalls of lateral chamber 36. Other portions of top layer 55 form the top of transfer channel 51, the tops of fill channels 119 and 120, and the tops of passages 39 and 40. A bottom surface of middle layer 54 may be welded or otherwise bonded to a portion of the top surface of bottom layer 53. A top surface of middle layer 54 may be welded or otherwise bonded to a portion of the bottom surface of top layer 55.

The construction of incline adjuster 16 is further understood by reference to FIGS. 5A through 5D3. FIG. 5A is a top view of bottom layer 53. Bottom layer 53 includes a flat panel 81 having a top surface 59. Except for an opening 60 that is part of fulcrum aperture 37, panel 81 is a continuous sheet. Layer 53 further includes a continuous conductive trace 116 formed on top surface 59. Trace 116 includes a bottom electrode 61 and an extension 62. Electrode 61 is positioned to extend over the portion of layer 53 that forms the bottom of transfer channel 51. As seen in more detail below, electrode 61 follows the path of and coincides with channel 51. Extension 62 branches away from the path of channel 51 and towards the rear edge of bottom layer 53. As explained in more detail below, extension 62 provides a location to electrically connect terminal 23b (FIG. 3) to electrode 61. In some embodiments, conductive trace 116 is a span of conductive ink that has been printed onto surface 59. The conductive ink used to form conductive trace 116 may be, e.g., an ink that comprises silver microparticles in a polymer matrix that includes thermoplastic polyurethane (TPU), and that bonds with TPU of panel 81 to form a flexible conductive layer. One example of such an ink is PE872 stretchable conductor available from E.I. DuPont de Nemours and Company.

In some embodiments, panel 81 is formed from two separate inner and outer sheets of polymeric material that have been laminated together. The outer sheet may be a 0.4 mm sheet of TPU having a Shore A durometer value of 85. An example of such a material includes a sheet formed from TPU resin having part number A92P4637 and available from Huntsman Corporation. In some embodiments, the outer sheet in panel 81 may be a 0.5 mm sheet of polyester-based TPU having a Shore A durometer value of 85. The inner sheet in panel 81 may be a 0.1 mm thick 2-layer polyurethane/polyurethane sheet in which one of the sheet layers is of higher durometer than the other of those two layers. Examples of such 2-layer of polyurethane/polyurethane sheets are commercially available from Bemis Associates Inc.

In some embodiments, layer 53 may be fabricated in the following manner. Prior to forming panel 81, conductive trace 116 is screen printed or otherwise applied to the higher durometer face of the inner sheet. The lower durometer face



of the inner sheet may then be placed into contact with an inner face of the outer sheet. The inner and outer sheets may then be laminated together by applying heat and pressure. Bottom layer 53 is then cut from the laminated sheets so that conductive trace 116 is in the proper location relative to outer edges and relative to opening 60.

FIG. 5B is a top view of middle layer 54 showing top surface 63 of middle layer 54. Middle layer 54 includes numerous open spaces that extend from top surface 63 to the bottom surface of middle layer 54. An open space 64 is isolated from other open spaces in layer 54 and is part of fulcrum aperture 37. Open space 127 forms side walls of medial fluid chamber 35. Open space 128 forms side walls of lateral fluid chamber 36. Open space 129 is connected to open spaces 127 and 128 and forms side walls of channel 51. Open spaces 131 and 132 are respectively connected to open spaces 127 and 128 and respectively form side walls of fill channels 119 and 120. Open spaces 133 and 134, which are isolated from each other and from other open spaces in layer 54, respectively form sides walls of access passages 39 and 40. In some embodiments, middle layer 54 is cut from a single sheet of TPU that is harder than TPU used in layers 53 and 55. In some such embodiments, the TPU used for layer 54 is 1.0 mm thick and has a Shore A durometer value of 92. An example of such a material includes a sheet formed from TPU resin having part number A85P44304 and available from Huntsman Corporation. Other examples of material that can be used for layer 54 include 1.0 mm thick TPU having a Shore D durometer value of 72 (e.g., a sheet formed from TPU resin having part number D7101 and available from Argotec, LLC) and 1.0 mm thick TPU having a Shore A durometer value of 87 (e.g., a sheet formed from aromatic polyether-based TPU resin having part number ST-3685-87 and available from Argotec, LLC).

FIG. 5C1 is a top view of top layer 55 showing top surface 52 of top layer 55. In FIG. 5C1, pockets 57 and 58 are convex structures. Medial pocket 57 is molded or otherwise formed into the sheet of top layer 55 on the medial side and forms the top and upper sidewalls of medial fluid chamber 35. Lateral pocket 58 is molded or otherwise formed into the sheet of top layer 55 on the lateral side and forms the top and upper sidewalls of lateral fluid chamber 36. Layer 55 may be formed from a relatively soft and flexible TPU that allows pockets 57 and 58 to easily collapse and expand so as to allow tops of chambers 35 and 36 to change height as ER fluid moves into and out of chambers 35 and 36. In at least some embodiments, and as explained below, top layer 55 may be formed from a 2-sheet lamination similar to that used for bottom layer 53.

FIG. 5C2 is a bottom view of top layer 55. Top layer 55 includes a panel 82 having a bottom surface 68. In FIG. 5C2, pockets 57 and 58 are concave structures. Layer 55 further includes a continuous conductive trace 135 formed on bottom surface 68. Trace 135 includes a top electrode 69 and an extension 70. Electrode 69 extends over the portion of layer 55 that forms the top of transfer channel 51. As seen in more detail below, electrode 69 follows the path of and coincides with channel 51. Extension 70 branches away from the path of channel 51 and towards the rear edge of top layer 55. As explained in more detail below, extension 70 provides a location for terminal 24b to electrically connect to electrode 69. In some embodiments, conductive trace 135 is a span of conductive ink that has been printed onto surface 68. The conductive ink used to form conductive trace 135 may be the same type of ink used to form conductive trace 116. FIG. 5C3, a partial area cross-sectional view taken from the location indicated in FIG. 5C2, shows additional details

of top electrode 69 and of pocket 58. Pocket 57 and other portions of top electrode may be similar. Except for an opening 66 that is part of fulcrum aperture 37, panel 82 is shown in FIG. 5C2 as a continuous sheet. In other embodiments, there may be additional openings or gaps in panel 82 (e.g., between portions of trace 135).

Panel 82 may comprise laminated inner and outer sheets of the same materials used to create panel 81. In some embodiments, layer 55 may be fabricated in the following manner. Prior to forming panel 82, conductive trace 135 is screen printed or otherwise applied to the higher durometer face of the inner sheet. The lower durometer face of the inner sheet may then be placed into contact with an inner face of the outer sheet. The two sheets may then be laminated together by applying heat and pressure. The laminated sheets are then thermoformed using a mold having cavities corresponding to the shapes of pockets 57 and 58. Care is taken during the thermoforming process to avoid damaging trace 135 and to properly position trace 135 relative to pockets 57 and 58. Layer 55 is then cut from the laminated and thermoformed sheets so that conductive trace 135 is in the proper location relative to outer edges and relative to opening 66.

FIG. 5D1 shows a first assembly operation when fabricating incline adjuster 16. As part of the first assembly operation, a first patch 139 is placed over a portion of conductive trace 116. In particular, patch 139 spans the width of electrode 61 in the region where branch 62 joins electrode 61, as well as the portion of branch 62 adjacent to electrode 61. In some embodiments, and as shown in FIG. 5D1, patch 139 is wider than branch 62. Patch 139 may be, e.g., a thin strip of TPU. In some embodiments the 0.1 mm inner sheet material used for panels 81 and 82 may also be used for patch 139, with the higher durometer side of the material placed toward trace 116. After placement of patch 139, middle layer 54 is placed onto bottom layer 53 so that a bottom surface 67 of middle layer 54 is in contact with top surface 59 of panel 81, and so that patch 139 is interposed between top surface 59 and bottom surface 67, as well as between portions of trace 116 and bottom surface 67. In some embodiments, alignment holes (not shown) may be formed in layers 53, 54, and 55 to assist in positioning during the operation of FIG. 5D1 and in subsequent assembly operations.

FIG. 5D2 shows a second assembly operation when fabricating incline adjuster 16. The left side of FIG. 5D2 shows layers 53 and 54 and patch 139 after the assembly operation of FIG. 5D1. Edges of patch 139 covered by middle layer 54 are indicated with broken lines. Electrode 61 extends over the portion of the layer 53 top surface that forms a bottom of channel 51. A portion of extension 62 extends over the portion of the layer 53 top surface that forms a bottom of access passage 39.

In the second assembly operation of FIG. 5D2, a second patch 140 is placed over a portion of conductive trace 135. In particular, patch 140 spans the width of electrode 69 in the region where branch 70 joins electrode 69, as well as the portion of branch 70 adjacent to electrode 69. In some embodiments, and as shown in FIG. 5D2, patch 140 is wider than branch 70. Patch 140 may also be, e.g., a thin strip of TPU. In some embodiments, patch 140 is cut from the same material used for patch 139 and is positioned with the higher durometer face toward trace 135. After placement of patch 140, assembled layers 53 and 54 (with interposed patch 139) are placed onto top layer 55 so that the bottom surface 68 of panel 82 is in contact with top surface 63 of middle layer 54,



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and so that patch 140 is interposed between top surface 63 and bottom surface 68, as well as between portions of trace 135 and top surface 63.

FIG. 5D3 shows layers 53, 54, and 55 after the assembly operation of FIG. 5D2. The positions of channel 51, channels 119 and 120, and passages 39 and 40 are indicated with broken lines. Although not visible in FIG. 5D3, electrode 69 extends over the portion of the layer 55 bottom surface that forms a top of channel 51. A portion of extension 70 extends over the portion of the layer 55 bottom surface that forms a top of access passage 40.

Layers 53, 54, and 55 and patches 139 and 140 may be bonded after assembly by RF (radio frequency) welding. In some embodiments, a multi-step RF welding operation is performed. FIGS. 8A and 8B are top views of two sides of an RF welding tool used in the first welding operation in some embodiments. FIG. 8A shows a side 401a that contacts the exposed bottom surface of bottom layer 53. Side 401a includes a wall 403a that extends outward from a planar base 405a. FIG. 8B shows a side 401b that contacts the exposed top surface 52 of top layer 55. Side 401b includes a wall 403b that extends outward from a planar base 405b. Wall 403b has a height above base 405b that is greater than the heights of pockets 57 and 58. As can be appreciated by comparing FIGS. 8A and 8B with FIG. 5D3, walls 403a and 403b include portions that correspond to the portions of middle layer 54 that define the shape of channel 51. Walls 403a and 403b further include portions that correspond to portions of middle layer 54 defining the sides of chambers 35 and 36, portions that correspond to portions of middle layer 54 defining passages 39 and 40, portions that correspond to portions of middle layer 54 defining the region between passages 39 and 40 and channel 51, and portions that correspond to portions of middle layer 54 defining the sides of channels 119 and 120.

Sides 401a and 401b may be attached to opposing sides of a fixture that is configured to press sides 401a and 401b together while RF frequency electrical power is applied to sides 401a and 401b. During the first RF welding operation, the assembly of FIG. 5D3 is placed between sides 401a and 401b, with side 401a contacting the bottom surface of layer 53 and side 401b contacting the top surface of layer 55, and with edges of walls 403a and 403b aligned with their corresponding portions of middle layer 54. In some embodiments, sides 401a and 401b are pressed together against the assembly (during application of electrical power) so as to compress regions of the assembly between the tops of walls 403a and 403b to a thickness at the end of the first RF welding operation that is 85% of the thickness prior to the first RF welding operation.

Subsequently, the assembly of FIG. 5D3 is subjected to a second RF welding operation. FIGS. 8C and 8D are top views of two sides of an RF welding tool used in the second welding operation in some embodiments. FIG. 8C shows a side 402a that contacts the exposed bottom surface of bottom layer 53. Side 402a includes a wall 404a that extends outward from a planar base 406a. FIG. 8D shows a side 402b that contacts the exposed top surface 52 of top layer 55. Side 402b includes a wall 404b that extends outward from a planar base 406b. Wall 404b has a height above base 406b that is greater than the heights of pockets 57 and 58. As can be appreciated by comparing FIGS. 8C and 8D with FIG. 5D3, walls 404a and 404b include portions that correspond to the portions of middle layer 54 that define the edges of chambers 35 and 36.

In the second RF welding operation, the assembly of FIG. 5D3 is placed between sides 402a and 402b, with side 402a

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contacting the bottom surface of layer 53 and side 402b contacting the top surface of layer 55, and with edges of walls 404a and 404b aligned with their corresponding portions of middle layer 54. In some embodiments, sides 402a and 402b are pressed together against the assembly (during application of electrical power) so as to compress regions of the assembly between the tops of walls 404a and 404b to a thickness at the end of the second RF welding operation that is 65% of the thickness at the start of the second RF welding operation.

In some embodiments, an intermediate RF welding operation may be performed between the first and second welding operations. In some such embodiments, tubes are inserted into the rear ends of channels 119 and 120. Those tubes are then sealed in place by applying sides of an RF welding tool around the rear ends of tabs 117 and 118. Those tubes and the portions of tabs 117 and 118 welded to those tubes may then be cut away after incline adjuster 16 is filled with ER fluid.

As previously indicated, incline adjuster 16 is configured for installation in a right shoe of a pair. An incline adjuster configured for installation in a left shoe of that pair may be a mirror image of incline adjuster 16. Accordingly, sides of RF welding tools used to fabricate that left shoe incline adjuster may be mirror images of the tool sides shown in FIGS. 8A through 8D.

Additional details of the regions of incline adjuster 16 that include patches 139 and 140 can be found in the U.S. provisional patent application 62/260,883 titled "Electrorheological Fluid Structure Having Strain Relief Element and Method of Fabrication", which application was filed on the same date as the present application and is incorporated by reference herein.

At the conclusion of the RF welding operations to bond layers 53, 54, and 55 and interposed patches 139 and 140, terminals 23b and 24b may be attached to portions of extensions 62 and 70 exposed in access passages 39 and 40. In some embodiments, terminals 23b and 24b are attached, and wires 23a and 24a RF welded in place, as described in the U.S. provisional patent application 62/260,890 titled "Electrorheological Fluid Structure With Attached Conductor and Method of Fabrication", which application was filed on the same date as the present application and is incorporated by reference herein.

After attachment of wires 23a and 23b, the housing of incline adjuster 16 formed by bonding of layers 53, 54, and 55 may be filled with ER fluid. FIG. 9 is a block diagram showing steps in a method of filling the incline adjuster 16 housing according to some embodiments. FIGS. 10A through 10K are partially schematic drawings showing operations associated with various steps in a method according to FIG. 9.

In step 501, ER fluid is introduced into the interior volume of housing 169 of incline adjuster 16. Housing 169 comprises bonded layers 53, 54, and 55 and patches 139 and 140. In some embodiments, and as shown in FIG. 10A, step 501 may include inserting a needle of a syringe 171 through fill channel 120 and into lateral fluid chamber 36. ER fluid is then injected. Fill channel 119 is left open so that air may escape as ER fluid fills chamber 36, transfer channel 51 and medial fluid chamber 35. FIG. 10B shows additional details of the filling operation. In FIG. 10B, a portion of top layer 55 has been removed to expose middle layer 54. For convenience, bottom electrode 61 and patches 139 and 140 are omitted from FIG. 10B. As the level of ER fluid 121 in chamber 36 rises, ER fluid 121 eventually flows into channel 51 and then into chamber 35. At the conclusion of step 501,



and as shown in FIG. 10C, chambers 36 and 35 and channel 51 are filled with ER fluid 121. ER fluid 121 also fills channels 119 and 120 to the levels indicated with arrows.

In step 503, filled housing 169 is placed into a vacuum chamber. FIG. 10D schematically shows housing 169 inside a vacuum chamber 172 while the interior of chamber 172 is at atmospheric pressure  $P_A$ . Atmospheric pressure  $P_A$  is the ambient air pressure and is, depending on geographic location, approximately 1 bar (14.7 psia). Subsequently, and as shown in FIG. 10E, chamber 172 is closed and a vacuum pump is activated. Air is withdrawn, thereby creating a sub-atmospheric pressure  $P_{SA}$  within chamber 172. Sub-atmospheric pressure  $P_{SA}$  is less than atmospheric pressure  $P_A$ . In some embodiments, sub-atmospheric pressure  $P_{SA}$  is  $10^{-3}$  (0.001) millibar or lower. In other embodiments, sub-atmospheric pressure  $P_{SA}$  may have a different value. Examples of different values for sub-atmospheric pressure  $P_{SA}$  in other embodiments include, without limitation,  $2 \times 10^{-3}$  (0.002) millibar or lower,  $3 \times 10^{-3}$  (0.003) millibar or lower,  $4 \times 10^{-3}$  (0.004) millibar or lower,  $5 \times 10^{-3}$  (0.005) millibar or lower,  $6 \times 10^{-3}$  (0.006) millibar or lower,  $7 \times 10^{-3}$  (0.007) millibar or lower,  $8 \times 10^{-3}$  (0.008) millibar or lower, and  $9 \times 10^{-3}$  (0.009) millibar or lower. In some embodiments, sub-atmospheric pressure  $P_{SA}$  may fluctuate within a range during step 503 and/or during step 507 (described below). For example, sub-atmospheric pressure  $P_{SA}$  may in some embodiments vary between  $10^{-3}$  (0.001) millibar and  $10^{-2}$  (0.01) millibar.

When ER fluid 121 inside housing 169 is exposed to sub-atmospheric pressure  $P_{SA}$ , and as also shown in FIG. 10E, air within ER fluid 121 comes out of solution and forms bubbles. As part of step 503, housing 169 remains at sub-atmospheric pressure  $P_{SA}$  for a period of time. During this time, air bubbles in fluid chambers 35 and 36 collect and rise, ultimately escaping through channels 119 and 120. As a result, the level of ER fluid 121 in channels 119 and 120 drops. Arrows included in FIG. 10F indicate the dropped levels of ER fluid 121 in channels 119 and 120. In some embodiments, housing 503 remains at sub-atmospheric pressure  $P_{SA}$  until it is visually determined that bubbles are no longer coming out of solution.

As further shown in FIG. 10F, air bubbles that formed in transfer channel 51 have also risen and collected. This results in formation of air pockets 173 in the channel bends that, in the current orientation of housing 169, form the highest points in channel 51.

Subsequently, the air pressure in vacuum chamber 172 is returned to atmospheric pressure  $P_A$  and housing 169 is removed from chamber 172. In step 505, and as shown in FIG. 10G, the needle of syringe 171 is reinserted into channel 120. A small amount of additional ER fluid 121 is introduced into chamber 36. This introduction of additional ER fluid 121 pushes the ER fluid already in chamber 36 into channel 51. In turn, this pushes air bubbles 173 along channel 51 and into chamber 35. Once in chamber 35, those air bubbles can escape through channel 119.

In step 505, only a small amount of additional ER fluid 121 is added. Thus, only ER fluid 121 in chamber 36 from which air was previously removed (in step 503) is pushed into channel 51. This prevents additional air pockets from forming in channel 51.

In step 507, housing 169 is returned to vacuum chamber 172. Chamber 172 is closed and a vacuum pump activated, again reducing the pressure inside chamber 172 and exposing ER fluid 121 in housing 169 to sub-atmospheric pressure  $P_{SA}$ . As shown in FIG. 10H, this causes air bubbles to form in the additional ER fluid 121 added to chamber 36 in step

505. Housing 169 is maintained at sub-atmospheric pressure  $P_{SA}$  for a period of time (e.g., until it is visually determined that bubbles are no longer coming out of solution). During that time, the air bubbles in chamber 36 collect and rise, ultimately escaping through channel 120.

FIG. 10I shows housing 169 after removal from vacuum chamber 172 at the end of step 507. ER fluid 121 in chamber 169 has been purged of air, and extends into channels 119 and 120 to levels indicated by arrows. Removal of air from ER fluid 121 will help to prevent malfunctioning of incline adjuster 16 during operation. In particular, the electrical field strength needed to arc across an air gap is approximately 3 kV/mm. This may be lower than the field strength needed to achieve sufficient viscosity increase in ER fluid 121 in channel 51. If air bubbles are present in channel 51 when an electrical field stronger than 3 kV/mm is imposed across electrodes 61 and 69, current may arc through those bubbles and result in collapse of the electrical field.

In step 509, channels 119 and 120 are sealed. The operation of step 509 is shown in FIG. 10J. Sides 175 and 176 of an RF welding tool are pressed across portions of channels 119 and 120 on the top surface of housing 169. Simultaneously, corresponding sides (not shown) of that RF welding tool are pressed across those same portions of channels 119 and 120 on the bottom surface of housing 169, and while electrical power is applied. As shown in FIG. 10J, the portions of channels 119 and 120 across which RF welding is performed are below the levels of ER fluid 121 in channels 119 and 120. Surprisingly, RF welding can be performed directly across a channel that contains ER fluid.

FIG. 10K shows completed incline adjuster 16 that results at the end of step 509. Subsequently, incline adjuster 16 may be incorporated into a sole structure, and that sole structure incorporated into a shoe.

In some embodiments, an incline adjuster may be modified to improve air removal. FIG. 11A shows an incline adjuster 716 according to one such embodiment. Except as described below, incline adjuster 716 is the same as incline adjuster 16 and can be fabricated in the same way (and using the same materials) as incline adjuster 16. Incline adjuster 716 differs from incline adjuster 16 with regard to the shapes of the rear portions of lateral fluid chamber 736 and medial fluid chamber 735. In particular, the rear portions of chambers 735 and 736 have more pronounced concave shapes that peak where connected to channels 719 and 720. This is shown in further detail in FIG. 11B, a top view of a middle layer 754 of incline adjuster 716. As seen in FIG. 11B, each of chamber 735 and chamber 736 has a rear region profile that smoothly progresses toward a connection to fill channel 719 or fill channel 720, and that does not include indentations or other regions where air bubbles might collect. The shapes of cavities 735 and 736 allow air to more easily escape through channels 719 and 720 during steps 503 and 507 of the method of FIG. 9.

FIG. 6 is a block diagram showing electrical system components of shoe 10. Individual lines to or from blocks in FIG. 6 represent signal (e.g., data and/or power) flow paths and are not necessarily intended to represent individual conductors. Battery pack 13 includes a rechargeable lithium ion battery 101, a battery connector 102, and a lithium ion battery protection IC (integrated circuit) 103. Protection IC 103 detects abnormal charging and discharging conditions, controls charging of battery 101, and performs other conventional battery protection circuit operations. Battery pack 13 also includes a USB (universal serial bus) port 104 for communication with controller 47 and for charging battery 101. A power path control unit 105 controls whether power



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is supplied to controller 47 from USB port 104 or from battery 101. A Reset button 106 activates or deactivates controller 47 and battery pack 13. An LED (light emitting diode) 107 indicates whether the controller is ON and the state of the electrical field. The above-described individual elements of battery pack 13 may be conventional and commercially available components that are combined and used in the novel and inventive ways described herein.

Controller 47 includes the components housed on PCB 46, as well as converter 45. In other embodiments, the components of PCB 46 and converter 45 may be included on a single PCB, or may be packaged in some other manner. Controller 47 includes a processor 110, a memory 111, an inertial measurement unit (IMU) 113, and a low energy wireless communication module 112 (e.g., a BLUETOOTH communication module). Memory 111 stores instructions that may be executed by processor 110 and may store other data. Processor 110 executes instructions stored by memory 111 and/or stored in processor 110, which execution results in controller 47 performing operations such as are described herein and in U.S. patent application Ser. No. 14/725,218, titled "Footwear Including an Incline Adjuster" and filed May 29, 2015, which application (in its entirety) is incorporated by reference herein. As used herein, instructions may include hard-coded instructions and/or programmable instructions.

IMU 113 may include a gyroscope and an accelerometer and/or a magnetometer. Data output by IMU 113 may be used by processor 110 to detect changes in orientation and motion of shoe 10, and thus of a foot wearing shoe 10. As explained in more detail below, processor 10 may use such information to determine when an incline of a portion of shoe 10 should change. Wireless communication module 112 may include an ASIC (application specific integrated circuit) and be used to communicate programming and other instructions to processor 110, as well as to download data that may be stored by memory 111 or processor 110.

Controller 47 includes a low-dropout voltage regulator (LDO) 114 and a boost regulator/converter 115. LDO 114 receives power from battery pack 13 and outputs a constant voltage to processor 110, memory 111, wireless communication module 112, and IMU 113. Boost regulator/converter 115 boosts a voltage from battery pack 13 to a level (e.g., 5 volts) that provides an acceptable input voltage to converter 45. Converter 45 then increases that voltage to a much higher level (e.g., 5000 volts) and supplies that high voltage across electrodes 61 and 69 of incline adjuster 16. Boost regulator/converter 115 and converter 45 are enabled and disabled by signals from processor 110. Controller 47 further receives signals from medial FSR 31 and from lateral FSR 32. Based on those signals from FSRs 31 and 32, processor 110 determines whether forces from a wearer foot on medial fluid chamber 35 and on lateral fluid chamber 36 are creating a pressure within chamber 35 that is higher than a pressure within chamber 36, or vice versa.

The above-described individual elements of controller 47 may be conventional and commercially available components that are combined and used in the novel and inventive ways described herein. Moreover, controller 47 is physically configured, by instructions stored in memory 111 and/or processor 110, to perform the herein described novel and inventive operations in connection with controlling transfer of fluid between chambers 35 and 36 so as to adjust the incline of the forefoot portion of the shoe 10 footbed 14.

FIGS. 7A through 7D are partially schematic area cross-sectional diagrams showing operation of incline adjuster 16, according to some embodiments, when going from a mini-

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mum incline condition to a maximum incline condition. In the minimum incline condition, an incline angle  $\alpha$  of the top plate relative to the bottom plate has a value of  $\alpha_{min}$  representing a minimum amount of incline sole structure 12 is configured to provide in the forefoot region. In some embodiments,  $\alpha_{min}=0^\circ$ . In the maximum incline condition, the incline angle  $\alpha$  has a value of  $\alpha_{max}$  representing a maximum amount of incline sole structure 12 is configured to provide. In some embodiments,  $\alpha_{max}$  is at least  $5^\circ$ . In some embodiments,  $\alpha_{max}=10^\circ$ . In some embodiments,  $\alpha_{max}$  may be greater than  $10^\circ$ .

In FIGS. 7A-7D, bottom plate 29, incline adjuster 16, top plate 41, FSR 31, FSR 32, and fulcrum element 34 are represented, but other elements are omitted for simplicity. FIG. 7E is a top view of incline adjuster 16 (in a minimum incline condition) and bottom plate 29 showing the approximate locations of the sectioning lines corresponding to the views of FIGS. 7A-7D. Top plate 41 is omitted from FIG. 7E, but the peripheral edge of top plate 41 would generally coincide with that of bottom plate 29 if top plate 41 were included in FIG. 7E. Although fulcrum element 34 would not appear in an area cross-section according to the section lines of FIG. 7E, the general position of fulcrum element 34 relative to the medial and lateral sides of other elements in FIGS. 7A-7D is indicated with broken lines.

Also indicated in FIGS. 7A through 7D are a lateral side stop 123 and a medial side stop 122. Medial side stop 122 supports the medial side of top plate 41 when incline adjuster 16 and top plate 41 are in the maximum incline condition. Lateral side stop 123 supports the lateral side of top plate 41 when incline adjuster 16 and top plate 41 are in the minimum incline condition. Lateral side stop 123 prevents top plate 41 from tilting toward the lateral side. Because runners proceed around a track in a counterclockwise direction during a race, a wearer of shoe 10 will be turning to his or her left when running on curved portions of a track. In such a usage scenario, there would be no need to incline the footbed of a right shoe sole structure toward the lateral side. In other embodiments, however, a sole structure may be tiltable to either medial or lateral side.

In some embodiments, a left shoe from a pair that includes shoe 10 may be configured in a slightly different manner from what is shown in FIGS. 7A-7D. For example, a medial side stop may be at a height similar to that of lateral side stop 123 of shoe 10, and a lateral side stop may be at a height similar to that of medial side stop 122 of shoe 10. In such embodiments, the top plate of the left shoe moves between a minimum incline condition and maximum incline condition in which the top plate is inclined to the lateral side.

The locations of lateral side stop 123 and of medial side stop 122 are represented schematically in FIGS. 7A-7D, and are not shown in previous drawing figures. In some embodiments, lateral side stop 123 may be formed as a rim on the lateral side or edge of bottom plate 29. Similarly, medial side stop 122 may be formed as a rim on the medial side or edge of bottom plate 29.

FIG. 7A shows incline adjuster 16 when top plate 41 is in a minimum incline condition. Shoe 10 may be configured to place top plate 41 into the minimum incline condition when a wearer of shoe 10 is standing or is in starting blocks about to begin a race, or when the wearer is running a straight portion of a track. In FIG. 7A, controller 47 is maintaining the voltage across electrodes 61 and 69 at one or more flow-inhibiting voltage levels ( $V=V_{fi}$ ). In particular, the voltage across electrodes 61 and 69 is high enough to generate an electrical field having a strength sufficient to increase the viscosity of ER fluid 121 in transfer channel 51



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to a viscosity level that prevents flow out of or into chambers 35 and 36. In some embodiments, a flow-inhibiting voltage level  $V_{fi}$  is a voltage sufficient to create a field strength between electrodes 61 and 69 of between 3 kV/mm and 6 kV/mm. In FIGS. 7A through 7D, light stippling is used to indicate ER fluid 121 having a viscosity that is at a normal viscosity level, i.e., unaffected by an electrical field. Dense stippling is used to indicate ER fluid 121 in which the viscosity has been raised to a level that blocks flow through channel 51. Because ER fluid 121 cannot flow through channel 51 under the conditions shown in FIG. 7A, the incline angle  $\alpha$  of top plate 41 does not change if the wearer of shoe 10 shifts weight between medial and lateral sides of shoe 10.

FIG. 7B shows incline adjuster 16 soon after controller 47 has determined that top plate 41 should be placed into the maximum incline condition, i.e., inclined to  $\alpha = \alpha_{max}$ . In some embodiments, controller 47 makes such a determination based on a number of steps taken by the shoe 10 wearer. Upon determining that top plate 41 should be inclined to  $\alpha_{max}$ , controller 47 determines if the foot wearing shoe 10 is in a portion of the wearer gait cycle in which shoe 10 is in contact with the ground. Controller 47 also determines if a difference  $\Delta P_{M-L}$  between the pressure  $P_M$  of ER fluid 121 in medial side chamber 35 and the pressure  $P_L$  of ER fluid 121 in lateral side chamber 36 is positive, i.e., if  $P_M - P_L$  is greater than zero. If shoe 10 is in contact with the ground and  $\Delta P_{M-L}$  is positive, controller 47 reduces the voltage across electrodes 61 and 69 to a flow-enabling voltage level  $V_{fe}$ . In particular, the voltage across electrodes 61 and 69 is reduced to a level that is low enough to reduce the strength of the electrical field in transfer channel 51 so that the viscosity of ER fluid 121 in transfer channel 51 is at a normal viscosity level.

Upon reducing the voltage across electrodes 61 and 69 to a  $V_{fe}$  level, the viscosity of ER fluid 121 in channel 51 drops. ER fluid 121 then begins flowing out of chamber 35 and into chamber 36. This allows the medial side of top plate 41 to begin moving toward bottom plate 29, and the lateral side of top plate 41 to begin moving away from bottom plate 29. As a result, the incline angle  $\alpha$  begins to increase from  $\alpha_{min}$ .

In some embodiments, controller 47 determines if shoe 10 is in a step portion of the gait cycle and in contact with the ground based on data from IMU 113. In particular, IMU 113 may include a three-axis accelerometer and a three-axis gyroscope. Using data from the accelerometer and gyroscope, and based on known biomechanics of a runner foot, e.g., rotations and accelerations in various directions during different portions of a gait cycle, controller 47 can determine whether the right foot of the shoe 10 wearer is stepping on the ground. Controller 47 may determine if  $\Delta P_{M-L}$  is positive based on the signals from FSR 31 and FSR 32. Each of those signals corresponds to magnitude of a force from a wearer foot pressing down on the FSR. Based on the magnitudes of those forces and on the known dimensions of chambers 35 and 36, controller 47 can correlate the values of signals from FSR 31 and FSR 32 to a magnitude and a sign of  $\Delta P_{M-L}$ .

FIG. 7C shows incline adjuster 16 very soon after the time associated with FIG. 7B. In FIG. 7C, top plate 41 has reached the maximum incline condition. In particular, the incline angle  $\alpha$  of top plate 41 has reached  $\alpha_{max}$ . Medial stop 122 prevents incline angle  $\alpha$  from exceeding  $\alpha_{max}$ . FIG. 7D shows incline adjuster 16 very soon after the time associated with FIG. 7C. In FIG. 7D, controller 47 has raised the voltage across electrodes 61 and 69 to a flow-inhibiting voltage level  $V_{fi}$ . This prevents further flow through transfer channel 51 and holds top plate 41 in the maximum incline

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condition. During a normal gait cycle, downward force of a right foot on a shoe is initially higher on the lateral side as the forefoot rolls to the medial side. If flow through channel 51 were not prevented, the initial downward force on the lateral side of the wearer right foot would decrease incline angle  $\alpha$ .

In some embodiments, a shoe may include an incline adjuster and other components that are configured to incline a different portion of a shoe footbed. As but one example, a basketball shoe may include an incline adjuster similar to incline adjuster 16, but having one chamber positioned in a medial midfoot or heel region, and another chamber positioned in a lateral midfoot or heel region, and with shapes of the chambers modified to match those positions. A controller of such a shoe could be configured to perform operations similar to those described above upon determining that a wearer's body position corresponds to a need to incline the midfoot and/or heel, and upon determining that such inclination is no longer needed. When cutting to the left, for example, a right shoe having a midfoot and heel region inclined medially could provide additional support and stability. A controller could be configured to determine that a cutting motion is occurring based on position and/or movement of the wearer's torso, and/or based on a sudden increase in pressure on a medial side of the shoe, and/or based on sensors located within an upper that indicate the heel region has tilted relative to the forefoot region.

A controller need not be located within a sole structure. In some embodiments, for example, some or all components of a controller could be located with the housing of a battery assembly such as battery assembly 13 and/or in another housing positioned on a footwear upper.

As can be appreciated from the above, incline adjuster 16 is a structure holding an ER fluid. Other embodiments include other structures that hold or that are configured to hold ER fluid and that have features similar to those described in connection with incline adjuster 16, but that may differ from incline adjuster 16 in one or more respects. Such structures, referred to herein as ER fluid structures for convenience, may be used in foot wear or in other applications.

In some embodiments, an ER fluid structure may include chambers having sizes and/or shapes different from those shown in above. Similarly, a transfer channel may have other sizes and/or shapes.

In some embodiments, an ER fluid structure may only have a single chamber, with one end of a transfer channel left open. That open transfer channel may subsequently be connected to another structure having an ER fluid reservoir or chamber, to a pump configured to transfer ER fluid from a separate reservoir or chamber, or to some other component.

In some embodiments, an ER fluid structure may not include chambers. For example, such a structure could be similar to the central portion of incline adjuster 16 that includes transfer channel 51 and access passages 39 and 40. Instead of connecting to chambers within the structure, however, the transfer channel ends may be open and connectable to separate components. Such a structure could be used, e.g., as a valve in an ER fluid system.

The foregoing description of embodiments has been presented for purposes of illustration and description. The foregoing description is not intended to be exhaustive or to limit embodiments of the present invention to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of various embodiments. The embodiments dis-



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cussed herein were chosen and described in order to explain the principles and the nature of various embodiments and their practical application to enable one skilled in the art to utilize the present invention in various embodiments and with various modifications as are suited to the particular use contemplated. Any and all combinations, subcombinations and permutations of features from herein-described embodiments are the within the scope of the invention. In the claims, a reference to a potential or intended wearer or a user of a component does not require actual wearing or using of the component or the presence of the wearer or user as part of the claimed invention.

The invention claimed is:

1. A method comprising:

introducing electrorheological fluid into an interior volume of a housing through a first channel connecting the interior volume with an exterior of the housing, while allowing air to exit through a second channel connecting the interior volume with the exterior of the housing, until the electrorheological fluid at least partially fills the first channel and the second channel, wherein the interior volume comprises first and second chambers connected by a serpentine third channel, wherein the first channel extends into the first chamber, and wherein the second channel extends into the second chamber; subjecting the electrorheological fluid within the housing to a sub-atmospheric pressure; removing the housing from a vacuum chamber; while the housing is removed from the vacuum chamber, and while one of the first and second channels remains open, injecting additional electrorheological fluid into the housing through the other of the first and second channels; after injecting the additional electrorheological fluid into the housing, returning the housing to the vacuum chamber; after returning the housing to the vacuum chamber, again subjecting the electrorheological fluid within the housing to a sub-atmospheric pressure; and sealing the interior volume relative to an exterior of the housing.

2. The method of claim 1, wherein the housing is a polymeric housing.

3. The method of claim 1, wherein the housing comprises an electrode coinciding with at least a portion of the third channel.

4. The method of claim 1, wherein the housing comprises first and second electrodes, each of the first and second

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electrodes coinciding with at least a portion of the third channel, and wherein the first and second electrodes are not in electrical contact with one another.

5. The method of claim 1, wherein the sealing comprises welding across a portion of the first channel containing a portion of the electrorheological fluid.

6. The method of claim 1, wherein the sealing comprises welding across a portion of the first channel containing a portion of the electrorheological fluid and welding across a portion of the second channel containing a portion of the electrorheological fluid.

7. The method of claim 1, wherein subjecting the electrorheological fluid within the housing to a sub-atmospheric pressure comprises subjecting the electrorheological fluid to a pressure less than a pressure at which the introducing step was performed.

8. The method of claim 1, wherein subjecting the electrorheological fluid within the housing to a sub-atmospheric pressure comprises subjecting the electrorheological fluid to a vacuum of  $10^{-3}$  millibar or lower.

9. The method of claim 1, wherein subjecting the electrorheological fluid within the housing to a sub-atmospheric pressure comprises subjecting the electrorheological fluid to the sub-atmospheric pressure during multiple intervals.

10. The method of claim 1, wherein the first channel extends through a first fill tab, wherein the second channel extends through a second fill tab, and wherein sealing the interior volume relative to the exterior of the housing comprises:

radio frequency welding across a portion of the first channel, in the first fill tab, containing a portion of the electrorheological fluid; and

radio frequency welding across a portion of the second channel, in the second fill tab, containing a portion of the electrorheological fluid.

11. The method of claim 1, wherein the serpentine third channel comprises three  $180^\circ$  curved sections joining other sections of the third channel that cover a space between the first and second chambers.

12. The method of claim 1, wherein an interior of the first chamber comprises a concave shape that peaks where the first channel connects to the first chamber, and wherein an interior of the second chamber comprises a concave shape that peaks where the second channel connects to the second chamber.

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